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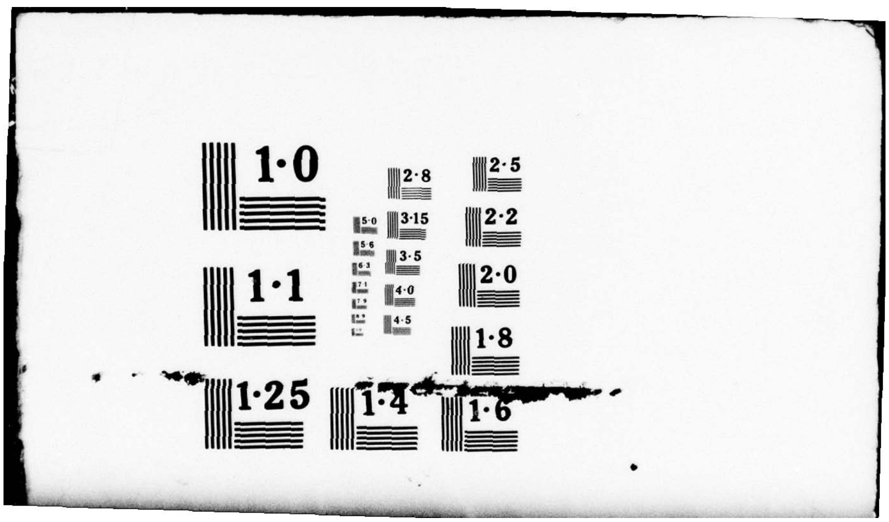
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LIMITED EVALUATION OF THE HOLLAND VERTICAL-CUT BELT LOADER

by

Charles E. Green

Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
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February 1979

Final Report

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This study was conducted to make a limited evaluation of the Holland vertical-cut belt loader on overburden and in situ coal. The evaluation was based on observations and data from various field demonstrations of the loader, articles from various industrial publications, physical and mechanical characteristics of two loader configurations, and engineering properties of in situ coal. The two loader configurations evaluated were the loader with Caterpillar D9G and Fiat Allis 41B tractors as prime movers. (Continued)

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20. ABSTRACT (Continued).

Estimates of earthmoving performance were made for the two configurations using the Army ground mobility methodology. The method applies to moving soil; however, it was modified to consider coal moving capabilities. The predicted performance was within the manufacturer's estimated range but closer to the conservative side of the range. Properly monitored field tests are needed on the vertical-cut belt loader to properly tune existing methodology and develop a reliable earthmoving prediction scheme.

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FOREWORD

This report was prepared by the U. S. Army Engineer Waterways Experiment Station (WES), Mobility and Environmental Systems Laboratory, P. O. Box 631, Vicksburg, Mississippi 39180, under USBM Contract No. H0252009. The contract was initiated under the Advanced Mining Technology: Coal Mining Program. It was administered under the technical direction of the Spokane Mining Research Center with Mr. Earl Frizzell acting as Technical Project Officer. Mr. Monte Camp was the contract administrator for the Bureau of Mines.

This report is a summary of the work completed as part of this contract during the period from July 1977 to February 1978.

Mr. W. G. Shockley, Chief, Mobility and Environmental Systems Laboratory (MESL), and Mr. E. S. Rush, Chief, Mobility Systems Division (MSD), MESL, were general supervisors of the study; Mr. C. E. Green, Research Engineer, Mobility Investigations Branch (MIB), MSD, MESL, directed it. The MSD is now one of the divisions of the Geotechnical Laboratory. Mr. Green also conducted the field observations, directed the data analysis, and wrote the report.

Acknowledgements are made to the following for cooperation and assistance in conducting the program:

Mr. Earl Frizzell, Spokane Mining Research Center
McKinley Mine Personnel, Pittsburg and Midway Mining Company
Mr. T. A. Haliburton, Oklahoma State University
Mr. T. L. Butkovich, Lawrence Livermore Laboratory

COL J. L. Cannon, CE, was Commander and Director of WES during the study and report preparation. Mr. F. R. Brown was Technical Director.

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CHAPTER 1: SUMMARY

This study was conducted to make a limited evaluation of the performance of the Holland vertical-cut belt loader while removing overburden from surface coal mines and mining of the coal beneath. Performance analysis study procedures were patterned after engineering models developed for evaluation of military ground vehicles in cross-country operations.

The evaluation was based on review and analysis of:

a. Observations and data from various field demonstrations of the loader.

b. Articles from various industrial publications.

c. Physical and mechanical characteristics of the two loader configurations.

d. Engineering properties of in situ coal.

Two prime mover configurations for the Holland loader (Caterpillar D9G and Fiat Allis 41B tractors) were evaluated to determine their performance on overburden (soil) and in situ coal. The following conclusions were drawn from the limited evaluation.

a. The Holland vertical-cut belt loader with either D9G or 41B prime movers appears to be capable of substantially fulfilling its manufacturer-predicted production rates provided it has adequate traction and can make a full, continuous cut in light to medium soils.

b. Sustained production rates will be much lower than the predicted maximums because relevant operating and environmental efficiency factors are not considered in the computations.

c. Conditions for optimum production did not exist at the Wyodak Mine, the Optima Dam construction site, or the hydroelectric plant construction site because the areas in which machines were operating did not allow the loader to make a full continuous cut.

d. Based on power available from the prime movers and power required to shear in situ coal, theoretical calculations indicate that the Holland loader with the D9G prime movers could not load in situ coal. The Holland loader with 41B prime movers could, however.

This study resulted in the following recommendations.

a. The Holland vertical-cut loader assembly with both prime mover configurations should be field tested in several types of overburden material and in situ coal to validate the theoretical estimates contained in this report.

b. Appropriate engineering data and detailed records of sustained production rates with the Holland vertical-cut loader in various types of material be maintained by the Bureau of Mines personnel in order to better evaluate its capabilities.

c. Drawbar pull-slip and pull-speed tests be conducted on a range of tractors to develop soil- and coal-vehicle relations for crawler tractors.

d. Laboratory tests to determine shear strength, density, and other pertinent physical parameters be conducted on coal from various coal mines located throughout the United States.

e. Field tests be conducted to determine the effective distance forward of the cutting edge at which coal will be sheared.

f. Carefully controlled tests be conducted to determine optimum production rates and the optimum tractor speed.

CHAPTER 2: INTRODUCTION

Background

The U. S. Bureau of Mines in June 1975 entered into an agreement with the Holland Construction Company to demonstrate the feasibility of the Holland vertical-cut belt loader in surface mining of coal and overburden removal. Unfortunately, the site selected for the demonstration was not satisfactory and the potential of the loader could not be evaluated. Subsequently, the Spokane Mining Research Center entered into an agreement with the U. S. Army Engineer Waterways Experiment Station (WES) to review available literature pertaining to the Holland loader and other similar loaders, and to collect readily available data that would help in making an evaluation of the vertical-cut belt loader for overburden removal and mining of coal.

Purpose

The purpose of the study was to make a limited evaluation of the performance of the Holland vertical-cut belt loader while removing overburden from surface coal mines and mining of the exposed coal.

Scope

The evaluation was based on review and analysis of the following items:

a. Progress reports and the final report submitted to the Spokane Mining Research Center by the Holland Construction Company under Contract No. H0252057 (Reference 1).

b. Data collected during a visit to the Wyodak Mine demonstration site by WES personnel (Reference 2).

c. Observations of performance of a horizontal-cut belt loader made by the Holland Construction Company in Garryowen, Montana (Reference 3).

d. Observations and data from Optima Dam construction site in Oklahoma (Reference 4).

e. Observations and data from a hydroelectric plant construction site in Illinois (Reference 5).

f. Information from various articles in industry publications and brochures (References 6-8).

g. Data from Oklahoma State University on physical and mechanical tests on coal samples.

h. Data from Lawrence Livermore Laboratory on physical and mechanical tests on coal samples.

i. Data from physical and mechanical tests conducted at WES on coal samples taken from the McKinley Mine at New Mexico.

CHAPTER 3: GENERAL DISCUSSION OF THE VERTICAL-CUT BELT LOADER

General Description

Figure 1 shows the general configuration of the loader. The loader is mounted between two tractors operating in tandem from single operator controls on the lead tractor. A modified gooseneck connection, mounted on the loader, ties the lead tractor to the machine. The rear tractor supports the loader through a dozer-like frame. The loader consists of a 15-ft-vertical and a 3-ft-horizontal cutting edge, along with a 40-ft-long conveyor belt system, which is driven by a 525-HP diesel engine. There is no vibration or oscillation associated with the blade movement; the loader depends on brute force to shear the vertical bank. The manufacturer-rated capacity is 3,600 to 10,800 cu yd/hr* depending upon certain conditions of the material being cut. Some external limiting factors on the production rates are: (a) characteristics of the material being moved, (b) traction characteristics of the material below the tractors, and (c) the availability of sufficient haul capacity to move the material away from the loader. The loader is supported by either two Caterpillar D9G or Fiat Allis 41B tractors (Figure 2) with synchronized throttles and controls. One operator on the lead tractor can operate the entire assembly (two tractors and the loader mechanism). The basic characteristics of the loader are summarized below.

Weight	95,000 lb (not including the tractors)
	241,500 lb (including 2-D9G tractors)
	380,000 lb (including 2-41B tractors)
Cutting edges;	
Vertical	15 ft
Horizontal	3 ft
Conveyor;	
Length	41 ft
Width	6 ft
Speed	up to 700 ft/min.

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented in Appendix A.

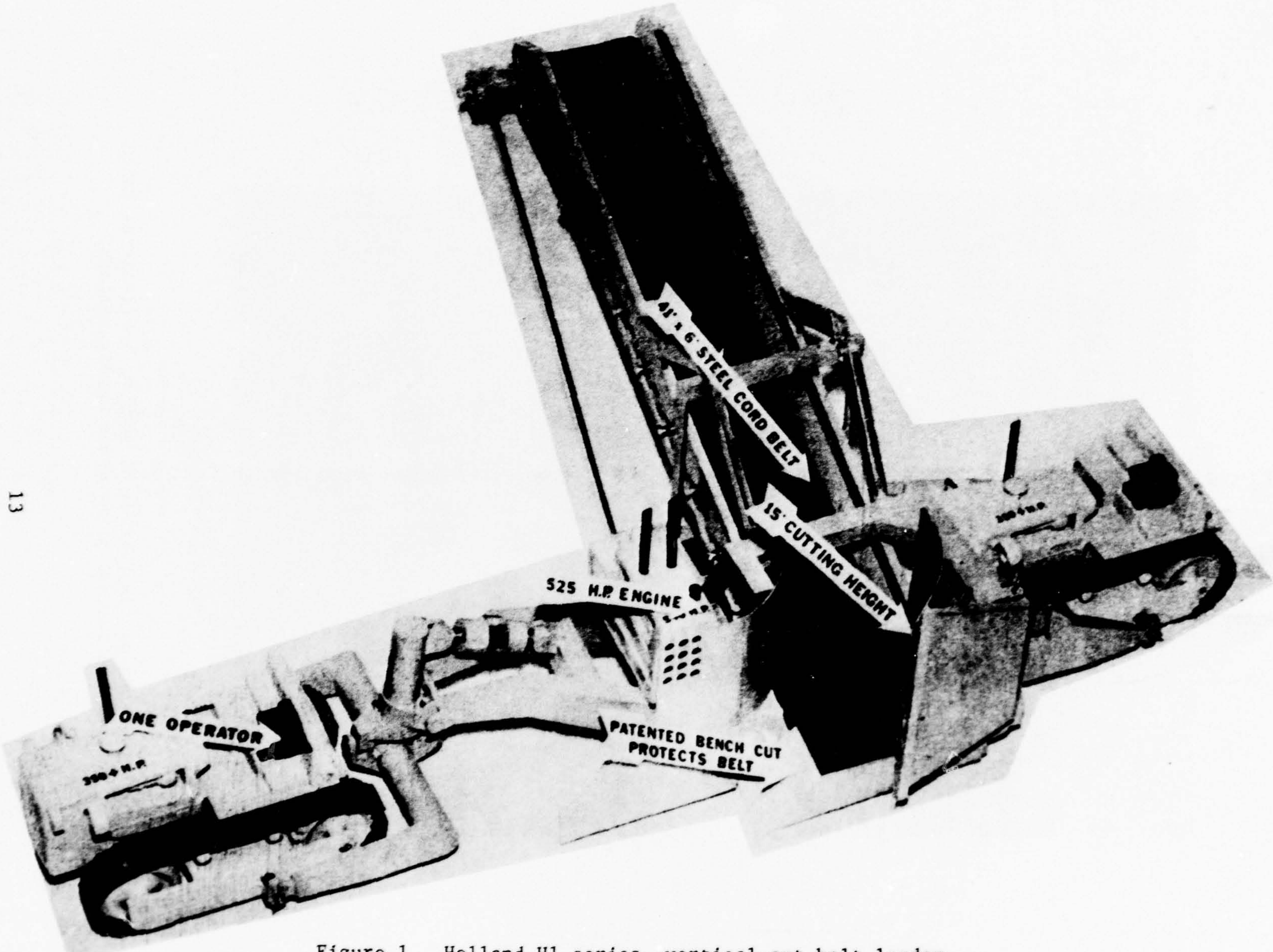
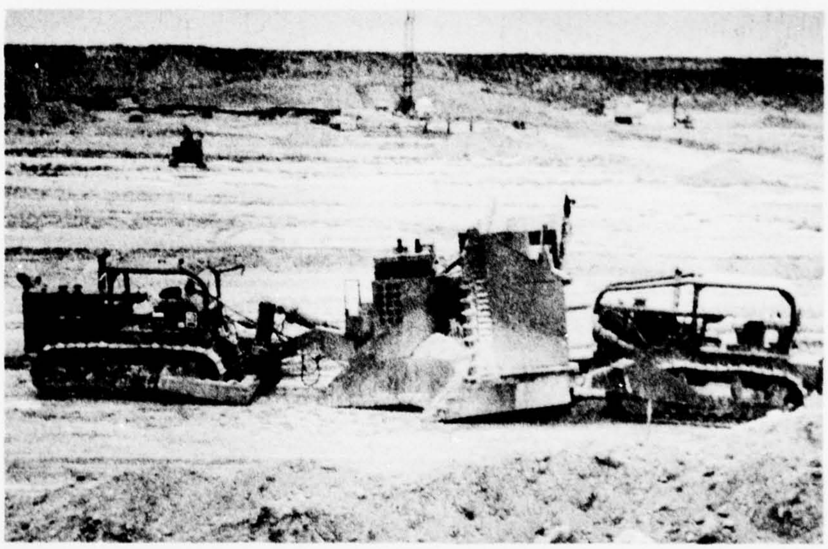


Figure 1. Holland H1 series, vertical-cut belt loader

a. D9G tractors



b. 41B tractors

Figure 2. Photographs of the Holland H1 series, vertical-cut belt loader with the two prime mover configurations

Fuel consumption (to move 25,000 cu yd under good conditions);

Loader	70 gal
Tractors	240 gal

Loader Operational Technique

The following information was extracted from Reference 1.

The hoist (lift) and tilt of the loader are accomplished by hydraulic cylinders, controlled with valves by the operator. An air compressor and air tank are attached to the loader engine and supply the air that is used by the operator to pneumatically:

<u>a</u>. Adjust the loader engine speed, which in turn starts the conveyor belt when 1000 rpm is reached.

<u>b</u>. Adjust the engine speeds of both the front and rear crawlers.

<u>c</u>. Apply the disk brake on the drive line to prevent the belt from moving backwards when loaded.

<u>d</u>. Disengage the steering clutches on the rear tractor for turns.

<u>e</u>. Shift the rear tractor from forward to reverse or vice-versa.

Once a cut face has been developed, the loader must be steered parallel to the face with the tractors roughly 2 to 3 ft from it. The depth of the cut is varied horizontally by varying the distance between the vertical cutting blade and the cut face, making it necessary for the operator to gauge his depth of cut as he travels. The vertical depth of cut is controlled by hydraulic adjustment of both tilt and hoist.

An increase in depth of cut is accomplished by tilting the loader toward the cutting face by means of the tilt cylinder or lowering it by means of the hoist cylinder. To reduce the depth of cut, it is necessary to tilt away from the cutting face or lift the hoist.

As the vertical and horizontal cutting edges are crowded into the vertical wall, forward motion of the loader cuts material from the bank. Most of this material falls onto a 3-ft bench left from the previous pass and is bladed onto the belt by the vertical moldboard. The remainder of the material is confined between the 3-ft bench and retaining

fence. The resistance between this material and the unexcavated bottom of the cut increases as the quantity of the material increases until the force is great enough to cause any additional material cut from the bank to flow directly into the throat and onto the belt.

Loader production is controlled during excavation by the depth of cutting into the vertical wall, use of the hoist tilt controls, and the operating speed of the belt.

The excavated material is loaded into large off-the-road trucks, usually belly dumps. As the trucks move into loading position, the belt must be stopped to avoid dropping excavated material on the cab of the truck. Starting from the rear of the truck body, the excavated material is fed into the truck. As the body fills, the truck slows slightly allowing the loader to advance relative to it. After the truck is filled, the loader may start travelling again as another truck pulls into position, and the process repeats itself.

When loading multiple body haulage units organized in a train, the vertical wall must be maintained as straight as possible. If it is not, the haulage train will not be able to follow the material flow from the belt, and unnecessary spillage will result.

CHAPTER 4: DISCUSSION OF DATA SOURCE REVIEWS

This part of the report discusses the reviews made of data and data sources listed earlier in this report (Scope, page 10).

Test/Demonstration at the Wyodak Mine

In June 1975, the Holland Construction Company entered into a contract with the U. S. Bureau of Mines to test and demonstrate the utility of a vertical-cut belt loader with Caterpillar D9G prime movers at the Wyodak Mine near Gillette, Wyoming (Reference 1). The planned objective was to strip a predetermined area of overburden from an underlying bed of coal. The original intention was to remove approximately 1,000,000 cu yd of overburden. The overburden depth in the planned test/demonstration area ranged from 15 ft near the edge of the existing pit to 100 ft near the outer limit of the mine boundary. Unfortunately, a law suit prevented operating in the planned area, and an alternate site was selected that was much less desirable for a test/demonstration. The overburden at the new site varied in depth from 0 to 15 ft, clearly not an ideal site to evaluate a loader with a 15-ft cutting blade.

Problems encountered in overburden removal

The demonstration at Wyodak Mine identified certain problems that will affect the performance of vertical-cut belt loaders when used in surface mining of coal and removal of overburden. The problems are as follows:

a. To test and demonstrate the vertical-cut belt loader, the project should be designed to minimize turnaround time and to provide maximum cutting surface.

b. The massiveness of the machine can cause some operating problems if wet soils are encountered.

c. Traction on the coal surface was inadequate for cutting the vertical wall of unshot coal. There were indications that rubber-tired tractors can develop more traction on coal surfaces than tracked tractors.

d. Certain materials, such as sand seams and shot coal, will not stand in a vertical cut, and loose material piled at the base of the cut prevents maximum production.

Performance on overburden

The maximum amount of material moved in one 5-day week (8 hr/day assumed) was 22,000 cu yd. Demonstrations elsewhere under more ideal conditions indicated movement of approximately 114,000 cu yd in one 5-day week (8 hr/day assumed). On a cubic yard per hour basis, the Wyodak production rate was only 19 percent of other demonstrated production rates. The owning and operating costs of the loader (and tractors) was computed to be $152/hr. In terms of cost per yard of material moved, this equates to $0.0533 at other demonstrated sites and $0.2764 at Wyodak.

Performance on coal

Attempts were made to excavate and load both shot and unshot coal at Wyodak. Shot coal was loaded with relative ease. However, production was low because of the shallow cut of the vertical blade. The shot coal does not readily stand in a vertical cut. Unshot coal could not be loaded because of resistances to shear along the 3-ft-horizontal "frog" and the vertical blade. These resistances caused loss of traction between the tracks and the coal surface. Side slipping of the tracks, particularly the rear tractor, also caused problems.

Conclusions and recommendations from the Wyodak demonstration

General conclusions of the Wyodak demonstration were:

a. The loader could not operate at peak efficiency because of various deterrent factors. Mainly the mine was not designed and developed for the vertical-cut type of overburden excavation.

b. Shot coal can be loaded without difficulty but at low efficiency because of the shape of the coal cutting surface after being shot.

c. The loader will not excavate unshot coal because of resistance to shear along the vertical face and loss of traction at the track coal surface interface.

As a result of field observations at Wyodak, recommendations were made for six modifications to improve the mining of unshot coal. Briefly, they were:

a. Install the basic loader on HD41B tractors. The 30 to 40 percent weight increase would reduce side slip of the rear tractor.

b. Move the rear tractor further to the rear. This would increase distance between the cutting edge and the tracks, thus reducing side slip of the rear tractor.

c. Reduce the surface of the track grouser bars to allow greater penetration into the coal surface. Increased traction could also be gained by (1) using the narrowest track possible, (2) using ice pads, and (3) installing a 10,000- to 12,000-lb counterbalance on the loader.

Site Characteristics and Observations by WES Personnel During Visit to Wyodak Mine

At the request of the Spokane Mining Research Center, WES personnel visited the Wyodak Mine (Reference 2) to observe a vertical-cut belt loader at work. Unfortunately, due to mechanical problems, the loader was inoperable at the time of the WES visit. In lieu of obtaining performance data on the loader, the mine and surrounding area were surveyed to obtain as much information as possible during the short visit.

General description of Wyodak Mine

The active portion of the mine is located immediately south of U. S. routes 14 and 16 and is easily visible from the highway. It is a pit-type operation, greatly resembling a limestone quarry. The overburden where mining activities were being conducted is thin, ranging from 3 to 5 ft, although this will change as the mine expands. Beneath the overburden are two coal layers separated by an 18-in. layer of saturated clay material. The top coal layer ranges in thickness from 15 to 35 ft, and the bottom layer is approximately 50 ft thick. Coal is mined in two trenches, and the intermediate clay material is removed by scrapers.

Production at the time of the visit was 750,000 tons/year but was being increased to 2,500,000 tons/year. Coal was loaded into belly-dump trucks and hauled to a processing plant immediately north of the highway. Because the ratio of overburden removed to coal removed is so small, reclamation in the usual sense is impossible, and a large hole will remain with nothing to fill it. The reclamation plan is to use available overburden material to grade the sides of the hole to slopes corresponding to natural areas in the vicinity.

Characteristics of the overburden

The Wyodak Mine is located in gently rolling terrain with a sparse, grassy vegetation cover. It is currently open range. A small stream (Donkey Creek) flows south of the mine and turns north, becoming the mines eastern boundary. At the time of the visit, the active part of the mine was located in a relatively flat alluvial area between nearby hills. The soil mass above the coal seam consists of dry, alluvial silty sands and clays. The system is generally layered-sandy material alternating with clays. The decomposed parent shales and limestones are still visible in cuts at the edges of the valley. The overburden material is very dry and firm, its strength exceeding the capacity of the cone penetrometer. A wet, soft layer caused by seepage from nearby Donkey Creek lies near the surface of the coal seam, however.

Soils data

A summary of soil data in the vicinity of the vertical-cut belt loader is given in the tabulation below. Location 1 was at the top of the overburden (about 15 ft thick) prior to any removal, location 2 was on the overburden when only about 5 ft of thickness remained, and location 3 was in the soft layer just above the coal seam as described earlier.

Location	Depth in.	Average Rating Cone Index	Moisture Content % of Dry Weight	Dry Density lb/cu yd
1	0-6	563	8.5	2802
	6-12	750+	10.0	2716
	12-18	750+	-	-

Location	Depth in.	Average Rating Cone Index	Moisture Content % of Dry Weight	Dry Density lb/cu yd
2	0-6	459	10.6	2716
	6-12	553	15.7	2818
	12-18	573	13.7	-
3	0-6	37	49.0	1458
	6-12	34	56.2	1534
	12-18	-	-	-

The low soil strength and high moisture content at location 3 support observations made in Reference 1. Traction was a problem for the prime movers. The rating cone index (RCI) of 34-37 brackets the calculated minimum RCI of 35 required to support the loader for one pass (RCI will be explored later). Had the soft layer been thicker, the loader would have been completely immobilized.

Summary

In the absence of any observational data or applicable prior experiences, no attempt was made to estimate the performance of the vertical-cut belt loader in overburden removal or coal mining at Wyodak. It did appear, however, that the loader could excavate the overburden in areas not affected by the wet material just above the coal surface. It also appeared that the loader could load loose, preshot coal from a smooth, level surface. It was less apparent, however, whether the loader would be able to function in unshot coal. It was also noted that operational and environmental factors needed for efficient loader operation did not exist at Wyodak.

Observation of Horizontal-Cut Belt Loader Performance

Observations were made of the performance of a horizontal-cut belt loader operating in a highway construction borrow pit near Garryowen, Montana (Reference 3). The horizontal-cut belt loader with D9G prime movers is basically similar to the vertical-cut belt loader with the main difference being orientation of the cutting blade and length of

blade cutting surface. The horizontal blade was 11 ft, 8 in. long compared with a 15-ft blade length on the vertical-cut belt loader. The horizontal blade also made a much narrower cut than the 3 ft possible with the vertical-cut loader.

The soil being worked by the horizontal-cut loader was field classified as CL (silty clay) with a RCI of 750+, a dry density of 2630 lb/cu yd, and a moisture content of 24 percent. The loader was observed to load 56-cu-yd haulers in an average time of one minute (3360 loose cu yd/hr) while traveling about 2 mph. The cutting distance was a little more than 100 ft per hauler load. Considerable delay was experienced waiting for empty haulers to return to the loading site after dumping their load.

Observation of Vertical-Cut Belt Loader Performance

Optima Dam construction site

Approximately 4,500,000 cu yd of material have been excavated in three years at this site with the loader (Reference 4). The material varied from a uniform sand-caliche mixture to well-cemented caliche and limestone. The RCI of the material was 750+. Explosives were required to break the limestone into pieces (< 1 cu ft in size) that the loader could handle. The maximum and average production rates were approximately 2200 cu yd/hr and 1250 cu yd/hr, respectively. The major reason for the relatively low average production rate was a lack of trucks to haul the material from the loader to the dam site (6 miles round trip). Using twelve 70-ton haul trucks, the loader spent about 40 percent of the time waiting for trucks. The project manager estimated it would take eighteen to twenty 70-ton trucks to keep the loader in continuous operation. The cut taken by the loader varied from 15 ft high by 0.5 ft wide to 5 ft high by 2 ft wide with an average being 10 ft high by 0.75 ft wide. The prime movers for the loader were Caterpillar D9G tractors.

Initial operation of the loader indicated some modifications were required for efficient operation. The rear unit (D9G) was having

traction and track wear problems, i.e., the tracks of the rear unit (D9G) were wearing five times faster than the tracks on the front unit (D9G). To minimize these problems a 6-ton concrete counterbalance was mounted on the loader to the rear of the vertical blade and opposite the conveyor belt. The track wear was reduced from the 5 to 1 ratio to a 2 to 1 ratio rear to front unit, and traction capabilities were increased.

The major problem with the loader at this site was conveyor belt wear. During the three-year period of operation the belt was replaced 15 times. Thirty-two man-hours were required to replace the belt. They are expensive (≈$9,000 each) and are not readily available.

Hydroelectric plant construction site

Approximately 1,500,000 cu yd of material have been excavated with the loader in 7 months at this site. The material was strip-mine tailings which consisted predominately of clayey sand. The RCI of the material was approximately 200. The maximum and average production rates were 3500 cu yd/hr and 2500 cu yd/hr, respectively. The average was somewhat lower than the machines capability due to a lack of trucks for hauling the material from the conveyor belt to the dump site (2 miles round trip). Using eight 50-ton haul trucks, the loader was idle approximately 40 percent of the time. The borrow area was oval shaped; therefore, the loader could make a continuous cut without wasting time turning around. The cut made by the loader varied from 15 ft high by 8 in. wide to 5 ft high by 3 ft wide with an average cut of 8 ft high by 2 ft wide. The prime movers for the loader were Fiat Allis 41B tractors.

Information from Various Articles and Industry Publications

Various articles from manufacturers brochures and industry publications (References 6-8) were reviewed to determine performance rates, job problems, and types of material excavated by vertical-cut belt loaders. Results of this review are given in the following paragraphs.

Holland loader brochure

In a borrow pit on an interstate highway construction job in Arizona, the loader with D9G prime movers excavated up to 25,000 cu yd per shift (assumed 10-hr shift or 2500 yd/hr) in material varying from good earth to caliche and cemented gravel (Reference 6). It is indicated that some excavation was made in material that could not be ripped by a D9 tractor. In the better material, 7200 cu yd/hr was excavated. Only $360 worth of cutter blade teeth were used while excavating 800,000 cu yd of material.

At another construction site, Perris Dam in California, three loaders reportedly excavated an average of 75,000 cu yd (25,000 cu yd per loader) per two-shift day (1250 cu yd/hr per machine assuming a 10-hr shift. Peak production was 120,000 cu yd per two-shift day (2000 cu yd/hr per loader). The excavated material was reported to be cemented limestone sand.

At a construction site in the state of Washington, the loader was reported to have loaded an average of 47 cu yd of material in an average time of 45 sec per load (3760 cu yd/hr). The material excavated was loose, harsh gravelly soil. Ninety to one hundred percent availability of equipment was reported, and less than two belts were needed to move some 3,500,000 cu yd of material.

In Montana, an average of 67-1/2 cu yd of unripped Bearpaw shale were excavated and loaded into haulers in an average time of 60 sec (4050 cu yd/hr).

Construction Methods and Equipment magazine

The CMI Corporation manufactures a self-propelled belt loading excavator named the Autovator (References 7-8). This machine is operated by one man and has the same type 15-ft vertical blade as the Holland belt loader. However, the width of the horizontal cut at the base of the loader is only 24 in. as compared with 36 in. on the Holland machine. One unique feature of the Autovator is its reversible blade, which permits operation in either direction eliminating the need to turn the entire machine around at the completion of a cut.

Powered by two 425-HP diesel engines, and driving eight 24-in.-wide crawler track assemblies, the Autovator is reportedly able to move about 4500 to 6000 cu yd/hr. At a power plant construction site in Arizona, an Autovator is reported to have moved 3000 cu yd/hr.

CHAPTER 5: WES EARTHMOVING PERFORMANCE METHODOLOGY

Soil-Vehicle Relations Used for Evaluation

The soil-vehicle relations used in evaluating the vertical-cut belt loader are the same as those used in the Army Mobility Model (AMM) (Reference 9), which was developed to estimate the performance of military vehicles operating on roads, trails, and cross country. The AMM normally outputs vehicle performance estimates in terms of vehicle speeds under specific terrain situations. The predicted soil-vehicle relationships are based on forces resulting from the interactions of the vehicle with soil surface materials. Output, therefore, can be expressed in force and other values that describe performance in terms of earthmoving rates, soil cutting forces, etc. In the case of the belt loader, the forces available from the traction of the prime movers are those forces used to shear the soil mass with the vertical and horizontal blades. For this analysis, other terrain aspects (such as slope, vegetation, and surface roughness that the AMM normally considers) were eliminated. The procedures for estimating the effects of soil properties, mainly soil strength as measured by RCI, on performance are given below.

The basic soil-vehicle parameters used to estimate performance are vehicle cone index, drawbar pull, and motion resistance.

Vehicle cone index (VCI)

VCI is the minimum soil strength in terms of RCI that will allow a specific vehicle to make a prescribed number of passes, usually one pass (VCI_1) or fifty passes (VCI_{50}). Note that RCI is strictly a function of soil strength, whereas VCI prescribes the soil strength (RCI) that is required to support a given vehicle. VCI, therefore, is a function of the vehicle being considered. VCI_1 is obtained by first computing a mobility index (MI), which is a dimensionless number obtained by applying certain vehicle factors to the formula in Tables 1 and 2, and then using the following equation:

$$VCI_1 = 7.0 + 0.2\ MI - [39.2 \div (MI + 5.6)]$$

Table 1

Mobility Index for Self-Propelled Tracked Vehicles in Fine-Grained Soils (D9G's)

Vehicle Holland Loader, Series H1 Weight 241,500 lb

Track Description 24" Wide Tandem D9H Prime Movers

$$\text{Mobility Index} = \frac{(1) \times (2)}{(3) \times (4)} + (5) - (6) \quad \times (7) \times (8)$$

(1) Contact Pressure Factor $= \dfrac{\text{Gross weight, lb}}{\text{Area of tracks in contact with ground, sq in.}} = \dfrac{241{,}500}{12{,}604} = 19.16$

(2) Weight Factor : <50,000 lb = 1.0; 50,000 to 69,999 lb = 1.2; 70,000 to 99,999 lb = 1.4; 100,000 lb or > = 1.8 = 1.8

(3) Track Factor $= \dfrac{\text{Track width, in.}}{100} = 24 \qquad = 0.24$

(4) Grouser Factor : <1.5 in. high = 1.0; >1.5 in. high = 1.1 = 1.1

(5) Bogie Factor $= \dfrac{\text{Gross wt} \div 10}{\text{Total no. bogies in contact with ground} \times \text{area of 1 track shoe}} \qquad = 2.66$

(6) Clearance Factor $= \dfrac{\text{Clearance, in.}}{10} = \dfrac{0}{10} \qquad = 0$

(7) Engine Factor = >10 hp/ton = 1.00; <10 hp/ton = 1.05 = 1.05

(8) Transmission Factor = Hydraulic = 1.00; Mechanical = 1.05 = 1.00

$$\text{Mobility Index} = \frac{19.16 \times 1.8}{.24 \times 1.1} + 2.66 - 0 \quad \times 1.05 \times 1.00$$

Mobility Index = 142

Vehicle Cone Index = 35

Table 2

Mobility Index for Self-Propelled Tracked Vehicles in Fine-Grained Soils (41B's)

Vehicle Holland Loader, Series H1 Weight 380,000 lb

Track Description 28" Wide Tandem 41B Prime Movers

$$\text{Mobility Index} = \frac{(1) \times (2)}{(3) \times (4)} + (5) - (6) \quad \times (7) \times (8)$$

(1) Contact Pressure Factor $= \dfrac{\text{Gross weight, lb}}{\text{Area of tracks in contact with ground, sq in.}} = \dfrac{380{,}000}{16{,}072} = 26.04$

(2) Weight Factor :
- <50,000 lb = 1.0
- 50,000 to 69,999 lb = 1.2
- 70,000 to 99,999 lb = 1.4
- 100,000 lb or > = 1.8

= 1.8

(3) Track Factor $= \dfrac{\text{Track width, in.}}{100} = 24$ = 0.28

(4) Grouser Factor :
- <1.5 in. high = 1.0
- >1.5 in. high = 1.1

= 1.1

(5) Bogie Factor $= \dfrac{\text{Gross wt} \div 10}{\text{Total no. bogies in contact with ground x area of 1 track shoe}}$ = 4.04

(6) Clearance Factor $= \dfrac{\text{Clearance, in.}}{10} = \dfrac{0}{10}$ = 0

(7) Engine Factor =
- >10 hp/ton = 1.00
- <10 hp/ton = 1.05

= 1.05

(8) Transmission Factor =
- Hydraulic = 1.00
- Mechanical = 1.05

= 1.00

$$\text{Mobility Index} = \frac{26.04 \times 1.8}{.28 \times 1.1} + 4.04 - 0 \quad \times 1.05 \times 1.00$$

Mobility Index = 164

Vehicle Cone Index = 40

VCI_1 for the vertical-cut belt loader with the D9G and 41B prime movers is 35 and 40, respectively, as shown in Tables 1 and 2.

Drawbar pull

Drawbar pull (DBP) is the amount of sustained force a vehicle can develop under given operating conditions. It is usually expressed in pounds, or as a dimensionless coefficient (DBP divided by vehicle weight). DBP varies with track slip for a given vehicle and operating condition (RCI). Maximum DBP usually occurs at 100 percent slip. This is not a meaningful parameter, however, because no useful work can be done if the vehicle is not moving forward. Usually an optimum DBP value occurs near 20 percent slip; this slip value represents the point at which the peak work output of the vehicle occurs. Optimum DBP at 20 percent slip versus soil strength as computed by AMM for the two prime mover configurations is shown in Figures 3 and 4.

Motion resistance

Motion resistance (MR) is the force developed by the soil in resisting the movement of a vehicle. It is assumed not to vary with slip or vehicle speed but to vary with soil strength (RCI). MR is usually expressed in pounds or as a dimensionless coefficient (MR divided by vehicle weight). MR versus RCI as computed by AMM for the two prime mover configurations is shown in Figures 5 and 6.

Vehicle speed-soil strength relations

To exercise the soil submodel of AMM, the theoretical tractive force-speed curve from the manufacturer's literature was adjusted for MR due to soil and plotted as effective DBP versus speed (Figures 7 and 8) for selected soil strength values for the two prime mover configurations.

Estimating Earthmoving Rates

Since the prime movers for the Holland loader can be either two Caterpillar D9G or two Fiat Allis 41B tractors, both cases are considered in the following paragraphs.

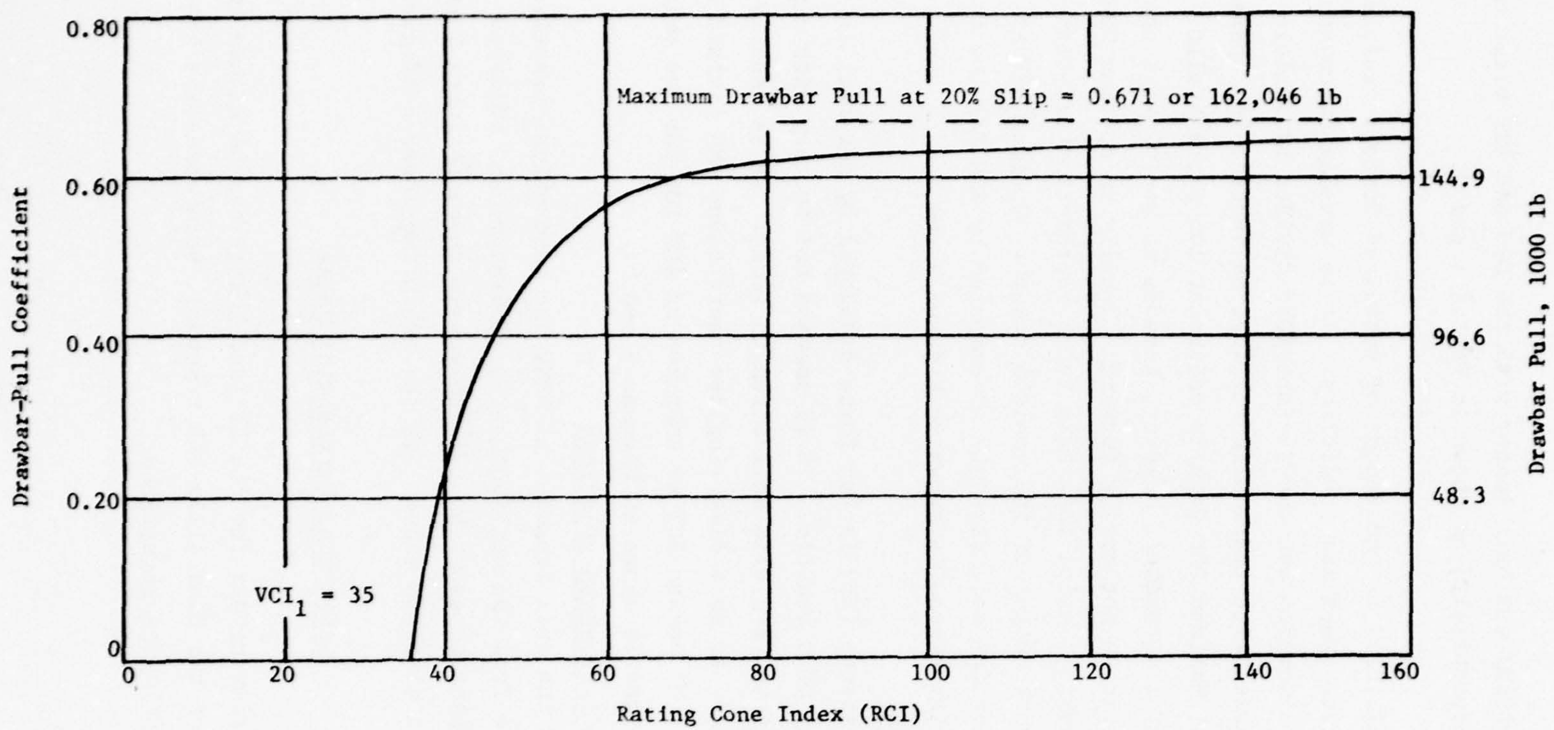


Figure 3. Optimum drawbar pull at 20 percent slip versus RCI, one pass, fine-grained soils, Holland loader, Series H1 with D9G prime movers, gross weight = 241,500 lb

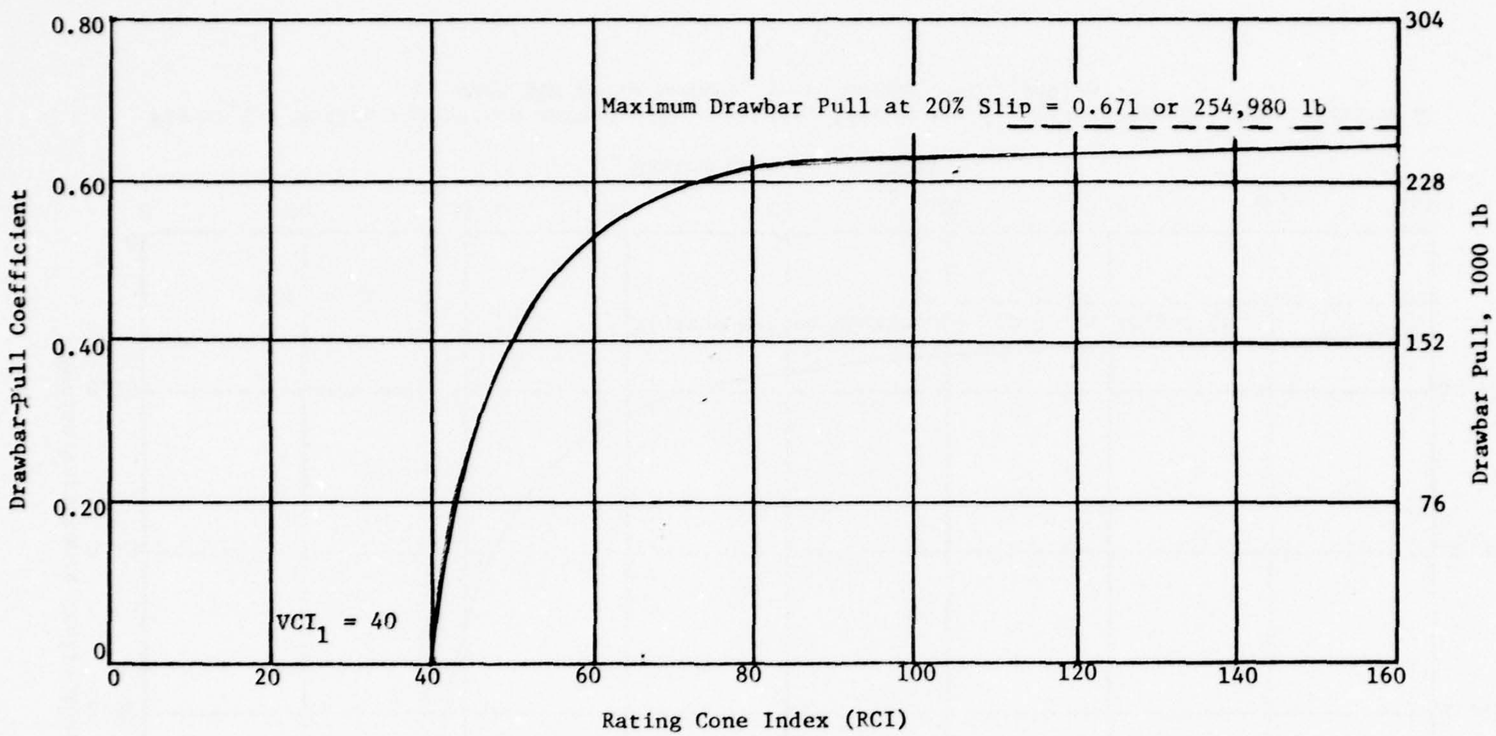


Figure 4. Optimum drawbar pull at 20 percent slip versus RCI, one pass, fine-grained soils, Holland loader, Series H1 with 41B prime movers, gross weight = 380,000 lb

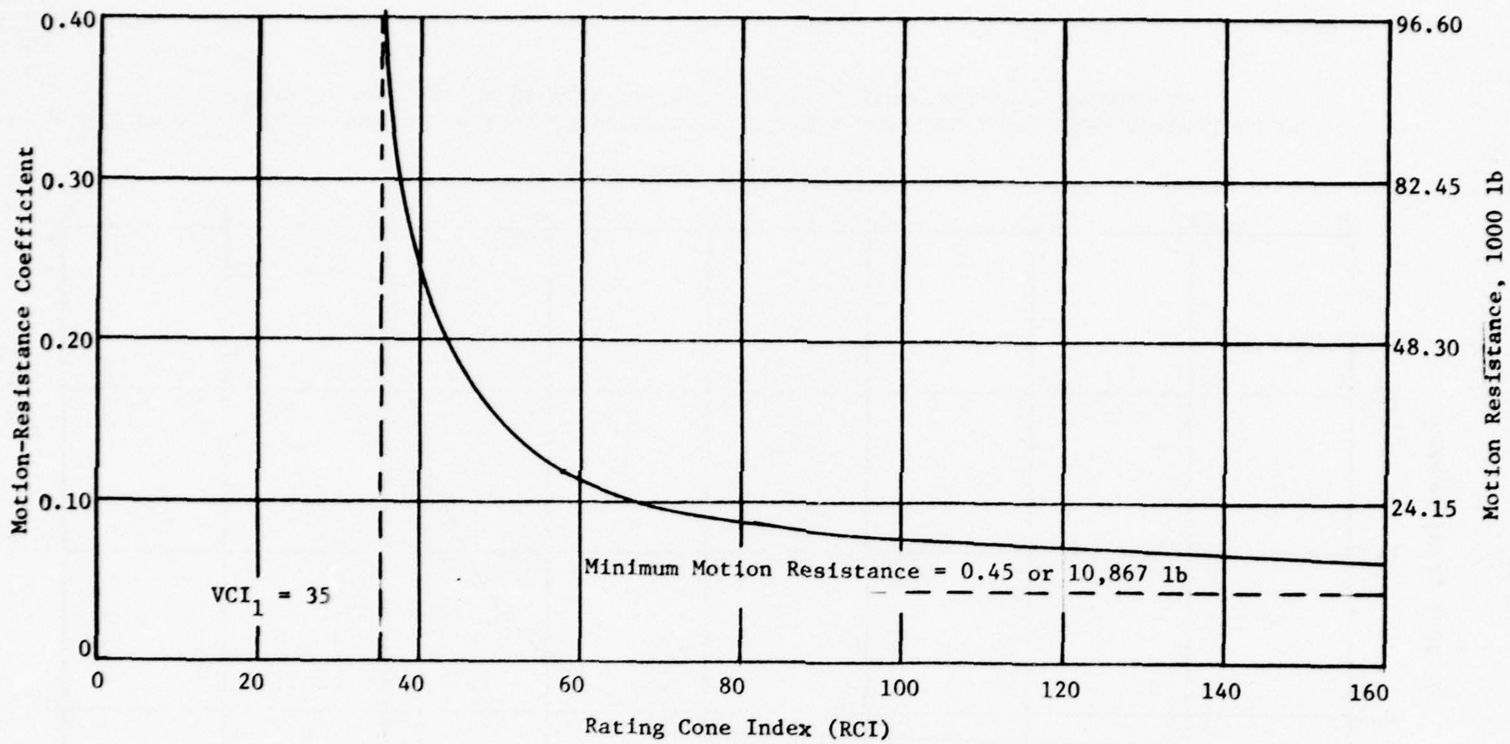


Figure 5. Motion resistance versus RCI, one pass, fine-grained soils, Holland loader, Series H1 with D9G prime movers, gross weight = 241,500 lb

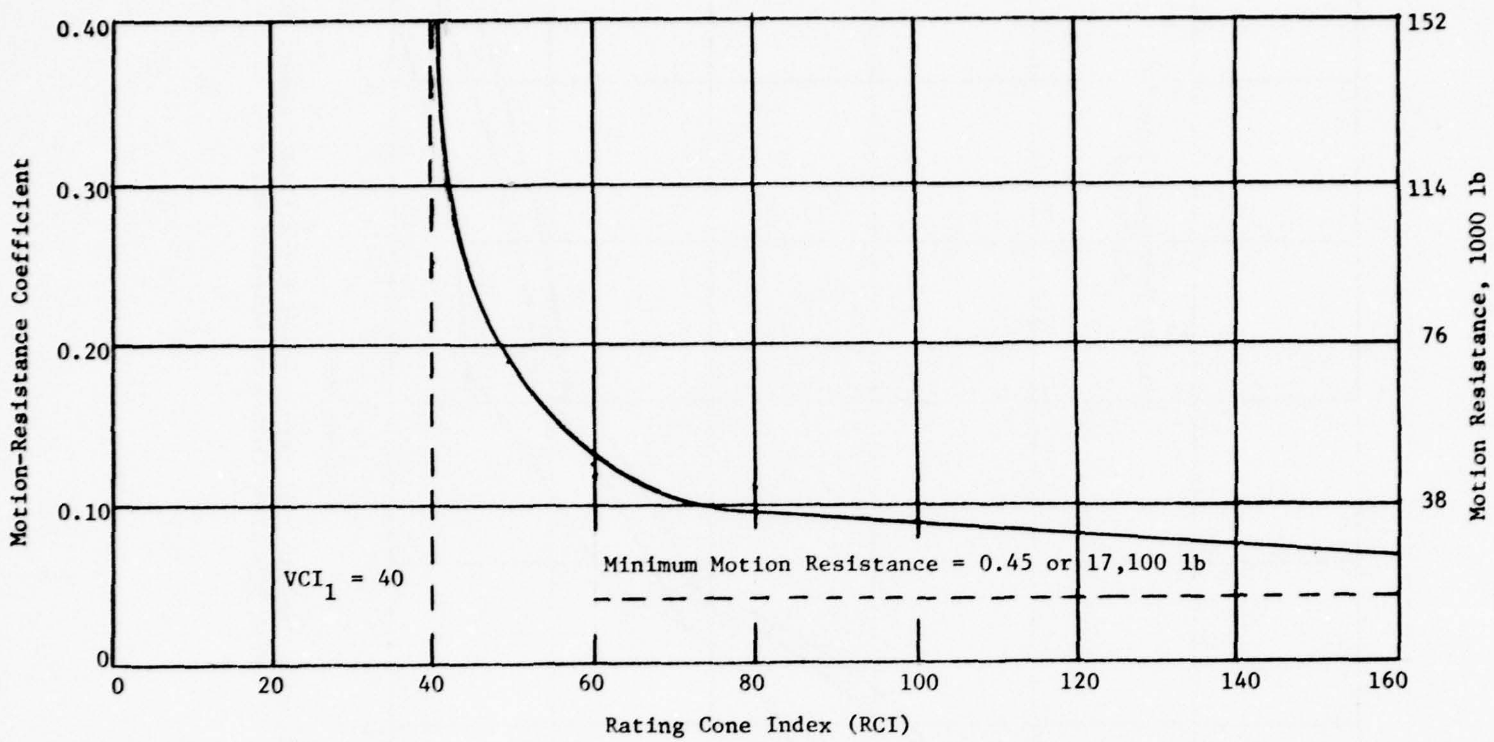


Figure 6. Motion resistance versus RCI, one pass, fine-grained soils, Holland loader, Series H1 with 41B prime movers, gross weight = 380,000 lb

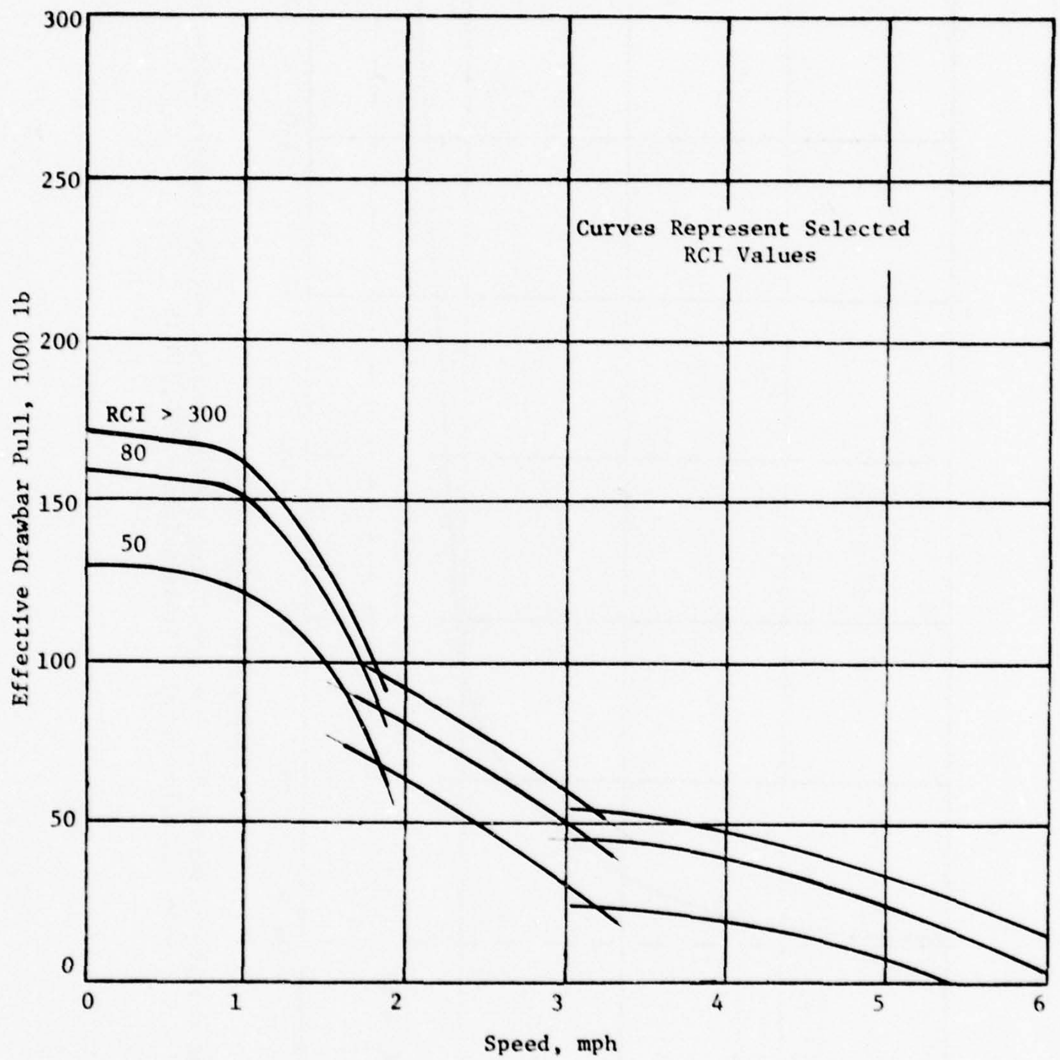


Figure 7. Effective drawbar pull versus speed for Holland loader, Series H1 with D9G prime movers on selected RCI's

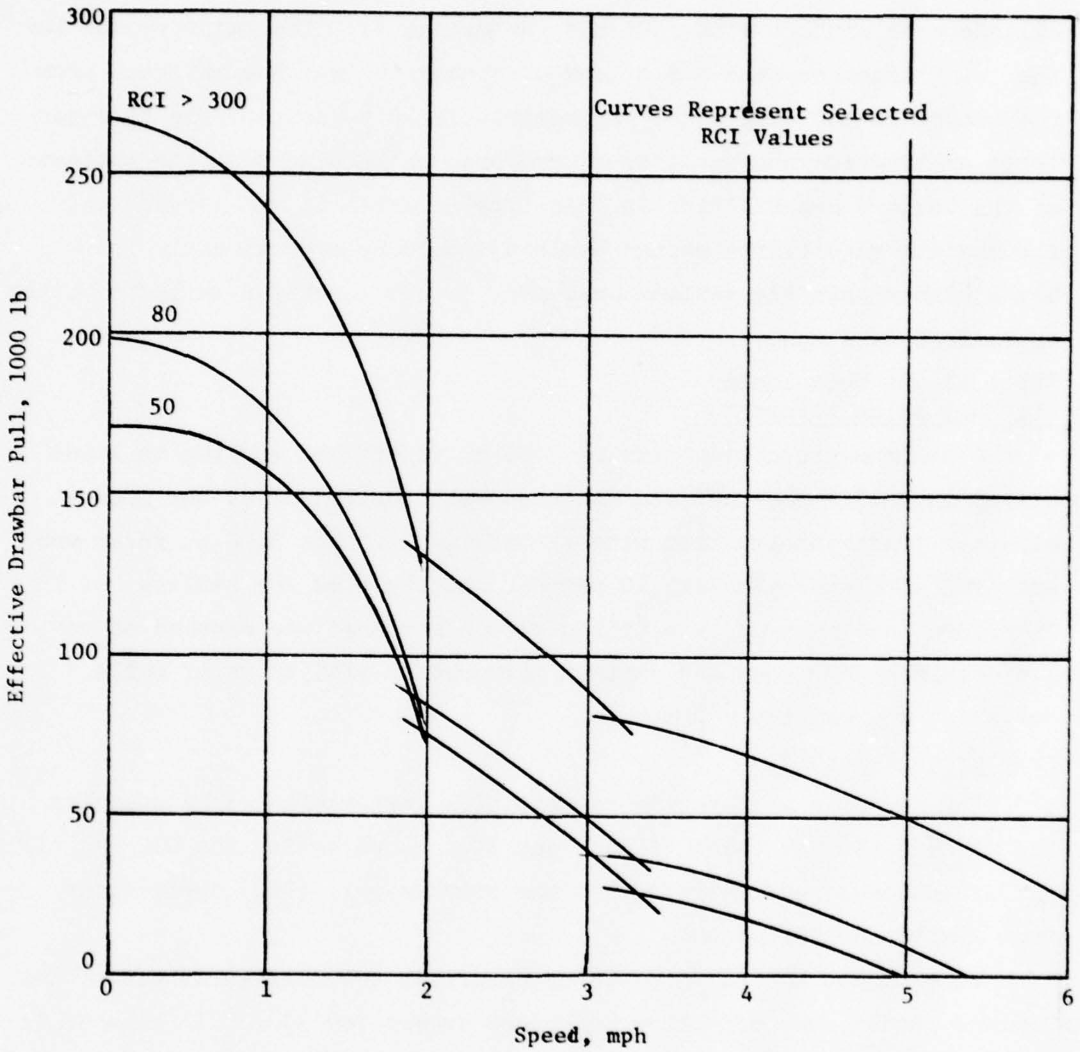


Figure 8. Effective drawbar pull versus speed for Holland loader, Series H1 with 41B prime movers on selected RCI's

Vertical-cut belt loader
with D9G prime movers

A maximum production rate of 2200 cu yd/hr was achieved with the loader at the Optima Dam construction site when working in a sand-caliche soil mixture with 750+ RCI (Reference 4). The major reason for the low production rate was a lack of trucks to haul the material from the loader to the dump site. Approximately 40 percent of the time was spent waiting for the haulers. Therefore, to make an adequate estimate of the loaders capabilities in this type material it was assumed that the maximum rate (given enough haulers) would be approximately 1.67 times higher than the maximum measured, or 3667 cu yd/hr while traveling approximately 2 mph.

Vertical-cut belt loader
with 41B prime movers

A maximum production rate of 3500 cu yd/hr when working in loose clayey sand with 300+ RCI was achieved with the loader at the hydroelectric plant construction site (Reference 5). The 3500 cu yd/hr was achieved with approximately 40 percent waiting time for haulers. Therefore, the maximum rate (given enough haulers) was assumed to be 1.67 times higher than the maximum measured or 5845 cu yd/hr while traveling approximately 2 mph.

Drawbar-pull method

The loader's earthmoving capabilities were estimated by applying the maximum haulage rates of 3667 and 5845 cu yd/hr for the D9G and 41B configurations, respectively, and the drawbar-pull (DBP) predictions from AMM to the DBP method.

To estimate the earthmoving rates of the two configurations of the Holland loader, the effective DBP-speed curves for 300+ RCI (Figures 7 and 8) were converted to productivity-speed curves as shown in Figure 9. The data used to develop these curves are given in Tables 3 and 4. The optimum rates are based on the traction capabilities of the machine rather than the size of the cutting blade. The soil was assumed to have an in situ density of 3250 lb/cu yd (2600-lb/cu-yd loose density) and the cutting distances were assumed to be in 100-ft segments.

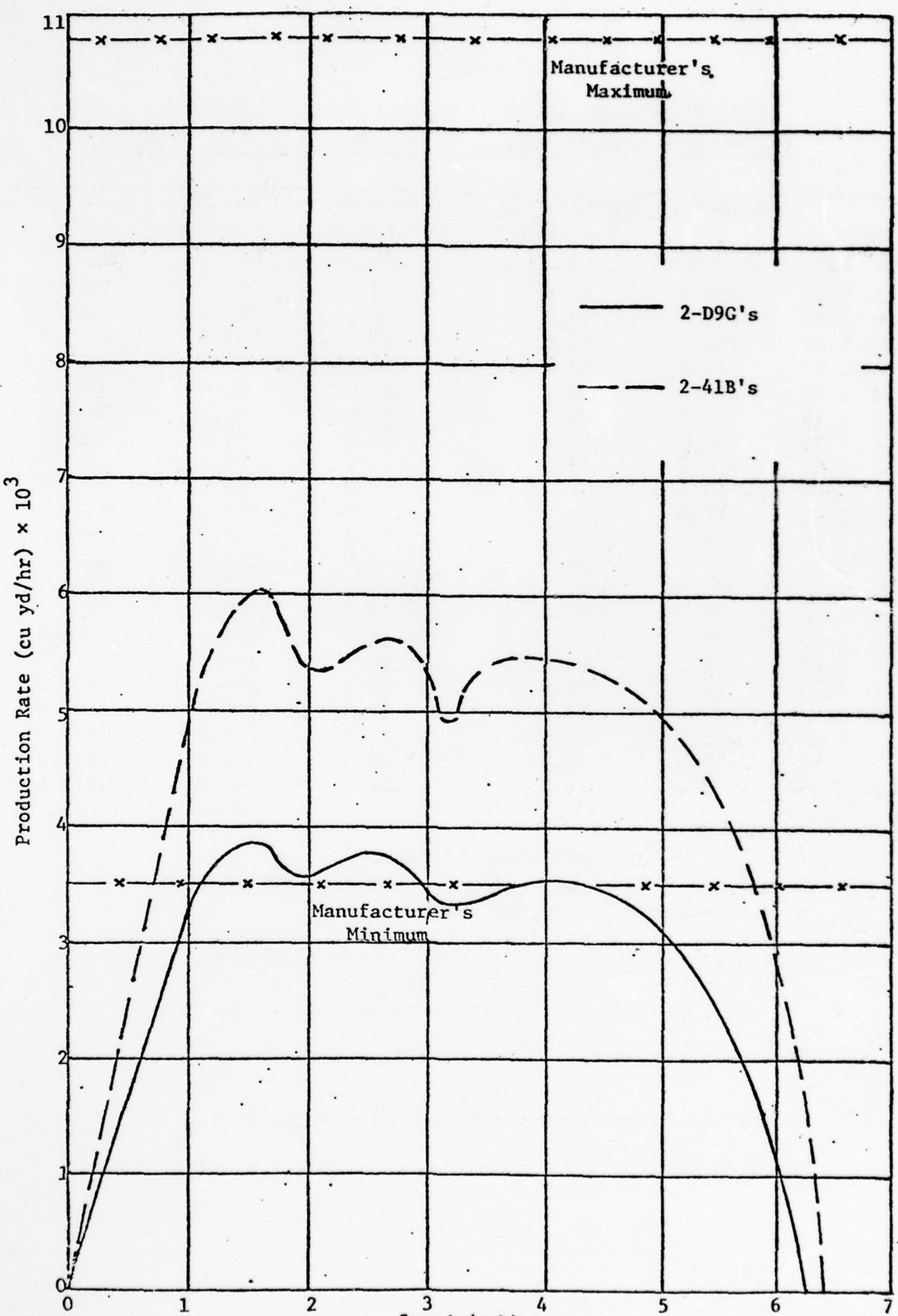


Figure 9. Estimated production rate versus speed for the Holland loader, Series H1

Table 3

Soil Production Based on Drawbar Pull and Speed for Holland Loader, Series H1 with Two-D9G Prime Movers

Speed		Effective Drawbar Pull		Seconds per 100-ft Section	100-ft Sections Per Hour	Loose cu yd/hr
mph	fps	lb x 1000	Equivalent cu yd			
0.2	0.29	168.0	64.6	344.8	10.4	672.0
0.4	0.59	167.0	64.2	169.5	21.2	1361.7
0.6	0.88	166.0	63.8	113.6	31.7	2023.9
0.8	1.17	163.0	62.7	85.5	42.1	2639.3
1.0	1.47	160.3	61.7	68.0	52.9	3261.5
1.2	1.76	149.0	57.3	56.8	63.4	3633.3
1.4	2.05	134.3	51.7	48.8	73.8	3812.1
1.6	2.35	118.0	45.4	42.6	84.5	3835.0
1.8	2.64	97.9	37.7	37.9	95.0	3577.1
2.0	2.93	88.0	33.8	34.1	105.6	3574.2
2.2	3.23	82.3	31.7	31.0	116.1	3675.0
2.4	3.52	75.3	29.0	28.4	126.8	3672.3
2.7	3.96	68.3	26.3	25.3	142.3	3738.1
2.9	4.25	60.3	23.2	23.5	153.2	3553.1
3.2	4.69	50.3	19.3	21.3	169.0	3269.5
3.4	4.99	48.3	18.6	20.0	180.0	3343.8
3.7	5.43	46.3	17.8	18.4	195.7	3489.0
3.9	5.72	44.3	17.0	17.5	205.7	3504.8
4.7	6.89	35.3	13.6	14.5	248.3	3371.2
5.2	7.63	27.3	10.5	13.1	274.8	2885.4
5.7	8.36	17.3	6.7	12.0	300.0	1996.2
6.2	9.09	3.3	1.3	11.0	327.3	415.4

Sample Calculation

Assume 2 mph (176 fpm) and RCI = 300 and 2600 lb/cu yd
From AMM, the DBP = 88,000 lb.

$$\text{Equivalent cu yd} = \frac{88{,}000 \text{ lb}}{2600 \times \dfrac{\text{lb}}{\text{loose cu yd}}} = 33.8 \text{ cu yd}$$

$$\text{Time to move 100 ft} = \frac{100}{176} \times 60 = 34.1 \text{ sec}$$

$$\text{No. of 100-ft sections per hour} = \frac{3600}{34.1} = 105.6$$

Loose cu yd/hr = 105.6 × 36.1 cu yd = 3574.2 cu yd/hr

Table 4

Soil Production Based on Drawbar Pull and Speed

for Holland Loader, Series H1 with Two-41B Prime Movers

Speed mph	Speed fps	Effective Drawbar Pull lb x 1000	Effective Drawbar Pull Equivalent cu yd	Seconds per 100-ft Section	100-ft Sections Per Hour	Loose cu yd/hr
0.2	0.29	264.75	101.8	344.8	10.4	1059.0
0.4	0.59	260.75	100.3	169.5	21.2	2126.1
0.6	0.88	254.75	98.0	113.6	31.7	3106.0
0.8	1.17	250.75	96.4	85.5	42.1	4060.2
1.0	1.47	237.75	91.4	68.0	52.9	4837.3
1.2	1.76	225.75	86.8	56.8	63.4	5504.8
1.4	2.05	190.75	73.4	48.8	73.8	5414.4
1.6	2.35	186.75	71.8	42.6	84.5	6069.4
1.8	2.64	155.75	59.9	37.9	95.0	5690.9
2.0	2.93	129.75	49.9	34.1	105.6	5269.9
2.2	3.23	120.75	46.4	31.0	116.1	5392.0
2.4	3.52	112.75	43.4	28.4	126.8	5498.7
2.7	3.96	102.75	39.5	25.3	142.3	5263.6
2.9	4.25	93.75	36.1	23.5	153.2	5524.0
3.2	4.69	75.75	29.1	21.3	169.0	4923.8
3.4	4.99	74.75	28.75	20.0	180.0	5175.0
3.7	5.43	72.75	28.0	18.4	195.7	5475.8
3.9	5.72	68.75	26.4	17.5	205.7	5439.2
4.7	6.89	54.75	21.1	14.5	248.3	5228.6
5.2	7.63	44.75	17.2	13.1	274.8	4729.7
5.7	8.36	32.75	12.6	12.0	300.0	3778.9
6.2	9.09	17.75	6.8	11.0	327.3	2234.5

Sample Calculation

Assume 2 mph (176 fpm), RCI = 300, and 2600 lb/cu yd
From AMM, DBP = 129,750 lb.

$$\text{Equivalent cu yd} = \frac{129{,}750 \text{ lb}}{2600 \times \dfrac{\text{lb}}{\text{loose cu yd}}} = 49.90 \text{ cu yd}$$

$$\text{Time to move 100 ft} = \frac{100}{176} \times 60 = 34.1 \text{ sec}$$

$$\text{No. of 100-ft sections per hour} = \frac{3600}{34.1} = 105.6$$

Loose cu yd/hr = 105.6 × 49.90 cu yd = 5269.9 cu yd/hr

Similar shaped curves could be computed for other soil strengths if desired. The curves for 300+ RCI show that the optimum speed is about 1.6 mph, and the calculated optimum earthmoving rates are about 3835 and 6069 cu yd/hr for the D9G's and 41B's, respectively. These values are compared with the estimated 3667 and 5845 cu yd/hr observed for the two configurations. Both values fall within the 3,600 to 10,800 cu yd/hr predicted by the manufacturer.

The next step was to determine the size of the cutting surface needed to match the optimum earthmoving rates based on traction capabilities. The cutting surfaces of the vertical-cut loader total 18 ft (15 ft vertical and 3 ft horizontal). Theoretically, the vertical-cut loader could shear 14,000 cu yd/hr at 1.6 mph if adequate traction were available. However, since traction limits the amount of earth moved, the entire blade surface available for shear cannot be used.

The allowable cut corresponding to an assumed vertical cutting length was computed using the following equation:

$$\frac{D \times V \times H}{27 \text{ cu ft/cu yd}} = E_R$$

where

D = distance traveled per hour (ft/hr)

V = height of vertical cut (ft)

H = width of horizontal cut (ft)

E_R = optimum earthmoving rate (cu yd/hr)

Solving for H

$$H = \frac{(27 \text{ cu ft/cu yd})\, E_R}{D \times V}$$

Using the above equation, an example of the calculations for each prime mover configuration is presented as follows:

a. D9G prime movers.

From Table 3 - at 1.6 mph, the effective drawbar pull = 118,000 lb and the optimum earthmoving rate (E_R) = 3,835 loose cu yd/hr. The distance (D) traveled in 1 hr at 1.6 mph = 8448 ft.

Then

$$H = \frac{(27 \text{ cu ft/cu yd})(3835 \text{ cu yd/hr})}{(8448 \text{ ft/hr})\ V} = \frac{12.26}{V}$$

Assuming V = 15 ft, then H = 0.82 ft.

b. 41B prime movers.

From Table 4 - at 1.6 mph, the effective drawbar pull = 186,750 lb the optimum earthmoving rate (E_R) = 6,069 cu yd/hr. The distance traveled in 1 hr at 1.6 mph = 8448 ft.

Then

$$H = \frac{(27 \text{ cu ft/cu yd})(6069 \text{ cu yd/hr})}{(8448 \text{ ft/hr})\ V} = \frac{19.40}{V}$$

Assuming V = 15 ft, then H = 1.29 ft.

The D9G and 41B prime movers when shearing a 15-ft vertical cut would thus shear horizontal cuts of 0.82 and 1.29 ft, respectively, given the optimum speed and earthmoving rate, based on available traction. By assuming other values for V , the vertical-horizontal ratios from maximum vertical to maximum horizontal were calculated and are shown graphically in Figure 10.

The earthmoving performance methodology used to convert predicted DBP values into production rates required that certain assumptions be made. Therefore, the production rates discussed above assume ideal conditions, i.e. 100 percent efficiency, 60 min of operating time per hour, zero turnaround time, constant working conditions, and so forth. In practice, efficiencies are much lower. For example, Reference 6 discusses an actual earthmoving operation in which three Holland vertical-cut loaders were involved. The maximum production achieved was 120,000 cu yd in a 20-hr day, or a sustained individual rate of 2000 cu yd/hr (33 cu yd/min). Normal production rates were 1250 cu yd/hr, or 21 cu yd/min. Compared with the manufacturer's maximum earthmoving estimates, this indicates an overall sustained efficiency of only 12 percent. This example is not intended to demean the manufacturer's estimates, but to emphasize that estimates of production capabilities should be based on sustained operations rather than short-term

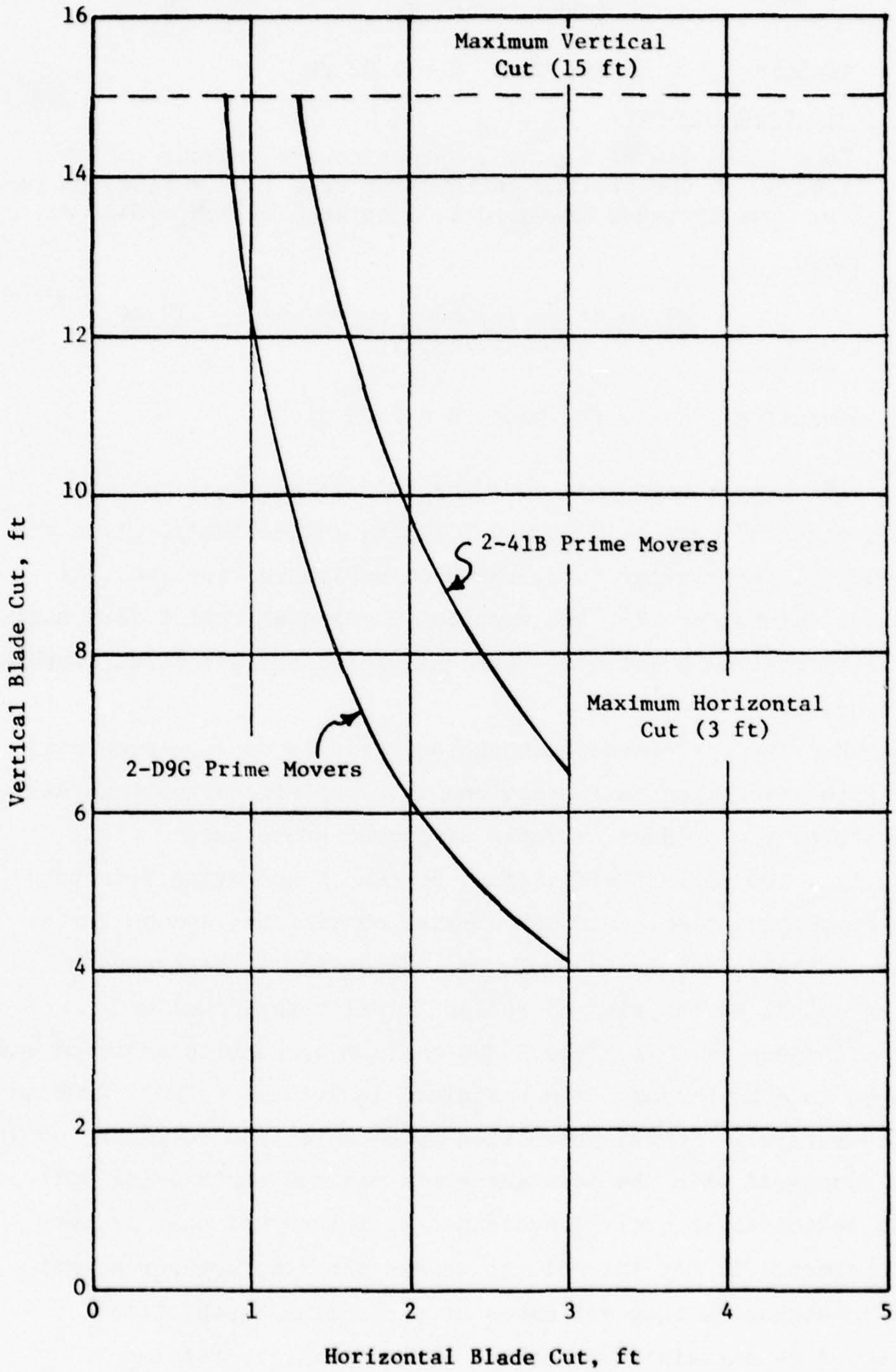


Figure 10. Vertical-horizontal cut ratio for optimum production

theoretical calculations and should consider more than one operational environment.

CHAPTER 6: ESTIMATING PERFORMANCE ON IN SITU COAL

Engineering Properties of In Situ Coal

To estimate the performance of the loader on in situ coal, some engineering properties of coal were required. To get an indication of the strength of in situ coal, results of engineering tests on coal were obtained from Oklahoma State University (OSU) and the University of California's Lawrence Livermore Laboratory. Additional tests were conducted by WES on coal samples from the McKinley Coal Mine, near Gallup, New Mexico.

Data from Oklahoma State University (OSU)

Unconfined compression tests were conducted on coal samples taken from a coal mine located approximately 10 miles southwest of Gillette, Wyoming. The average unconfined compressive strength for these samples was 343 psi.

Data from Lawrence Livermore Laboratory

Triaxial tests were conducted by Lawrence Livermore Laboratory on Powder River and Hoe Creek coal samples. The Powder River and the Hoe Creek samples were taken near Lake De Smet and Gillette, Wyoming, respectively. The average shear stress intercept was approximately 350 psi.

Data from laboratory tests conducted at WES

Using standard techniques, five Brazilian tests and six direct shear tests were conducted on McKinley Mine coal samples. All the Brazilian tests and four of the shear tests were conducted parallel to the bedding plane of the coal. Two shear tests were conducted perpendicular to the bedding plane of the coal. The results of these tests are shown in the following tabulations.

Brazilian Test Results

Test No.	Density pcf	Shear Stress psi
1	80.1	474
2	77.9	253
3	77.5	174
4	77.8	293
5	79.8	424
Average	78.6	324

Direct Shear Test Results

Test No.	Bedding Orientation	Normal Stress (σ_n)(psi)	Shear Stress (T)(psi)
1	Parallel	49.8	193.5
2	Parallel	70.2	296.3
3	Parallel	90.3	317.7
4	Parallel	171.7	383.5
Average			297.8
5	Perpendicular	44.1	373.3
6	Perpendicular	108.1	583.8
Average			478.6

Mohr's envelopes developed from the results of the direct shear tests are shown in Figure 11. Using the least squares method for determining the line of best fit, the angle of internal friction (ϕ) and the shear stress intercept (c) was determined to be 52.7 deg and 172.5 psi parallel to the bedding and 73.1 deg and 228.3 psi perpendicular to the bedding.

Near the cutting face of the Holland loader, the normal stress will be very small, so the shear strength at zero stress should be applicable. However, due to the limited number of tests conducted, the average shear stresses from the Brazilian tests and the direct shear tests were averaged to determine a shear value for use in estimating the performance of the loader. The average shear stress was 367 psi and average density was 78.6 pcf or 2122 lb/cu yd. Although the average density was somewhat lower than expected, it was used for estimating the loader's performance.

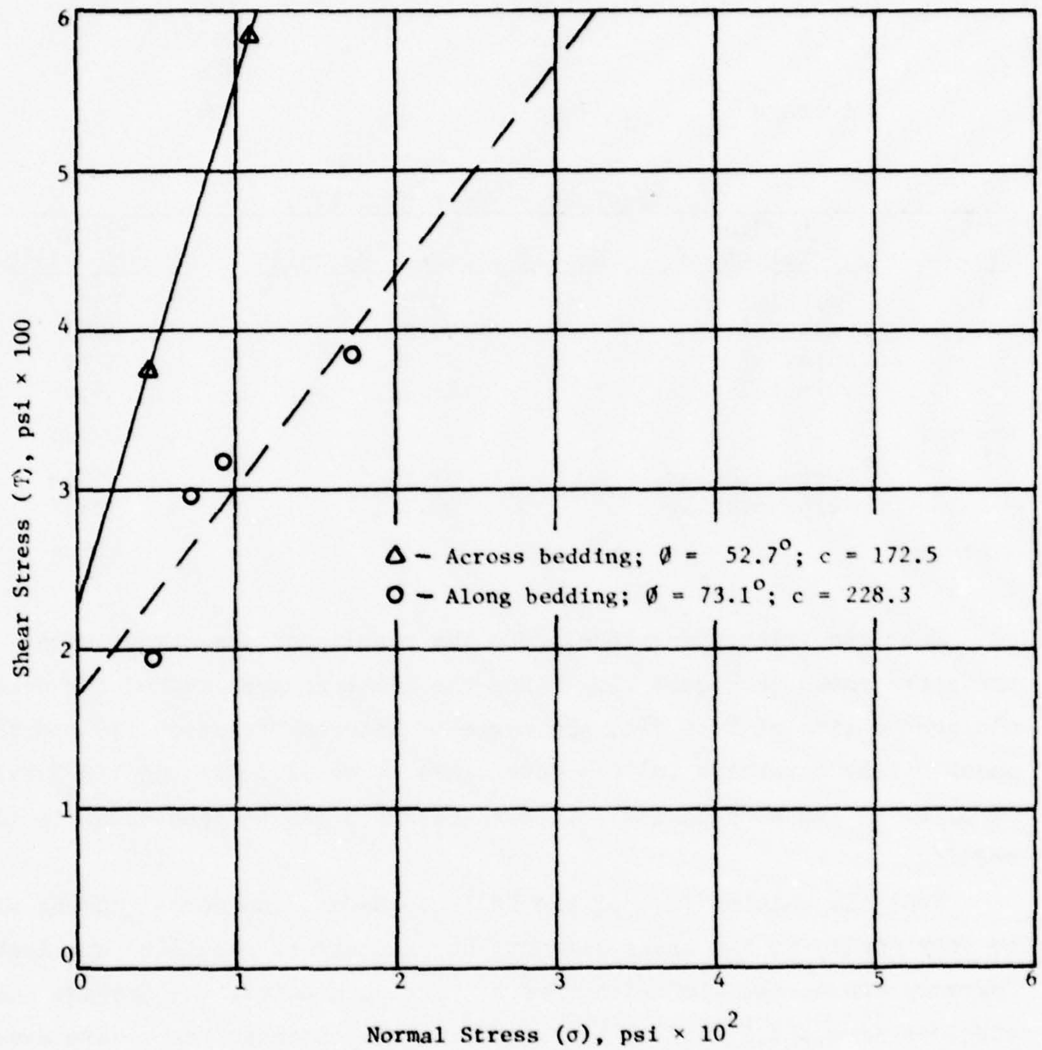


Figure 11. Shear stress versus normal stress for McKinley Mine Coal samples

Pertinent Physical Characteristics of the Loader

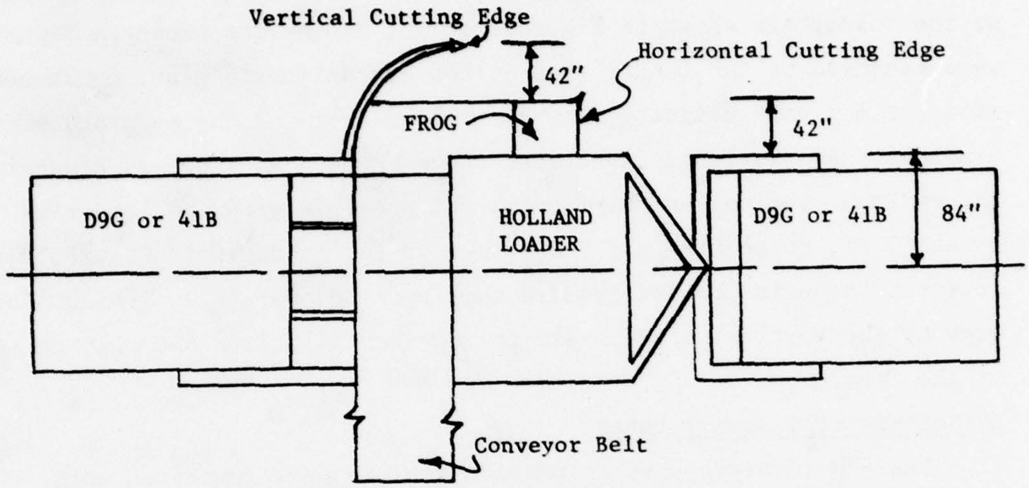
A generalized top view and generalized views of the cutting edges of the loader are shown in Figure 12. The dimensions shown in Figure 12 were measured on the loader used at the hydroelectric plant construction site and may vary slightly from dimensions shown on the manufacturer's drawings. As previously mentioned (page 12) and as shown in Figure 12, the maximum vertical and horizontal cut possible with the loader is 15 and 3 ft, respectively. (Note that 42 in. is shown in Figure 12; however, the prime movers require some room to operate.) The cutting edge of the vertical blade is 42 in. horizontally from the cutting edge of the frog.

Estimating coal moving rates

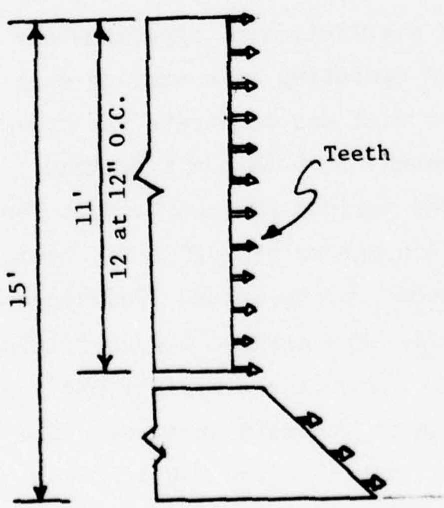
The AMM is structured to predict vehicle performance on soil. To adequately predict vehicle performance on in situ coal, therefore, the DBP predictions had to be modified. The procedure used for modification is discussed in the following paragraphs.

Normally when a tracked vehicle (without road pads) is operating on a soil with 300+ CI, the track's grousers will penetrate the soil surface, thereby resulting in a maximum DBP coefficient of approximately 0.67. However, when a tracked vehicle is operating on a surface much harder than 300+ CI, the track's grousers will not penetrate the surface, resulting in a DBP coefficient somewhat less than the maximum stated above. To get an indication of the maximum DBP coefficient for tracked vehicles operating on surfaces much harder than 300+ CI, tests conducted on a concrete surface by Aberdeen Proving Ground (Reference 10) with 17 tracked vehicles were reviewed. The maximum DBP coefficients for all the test vehicles were averaged to determine a maximum DBP coefficient for tracked vehicles operating on concrete surfaces. The average maximum DBP coefficient for the 17 vehicles was 0.45.

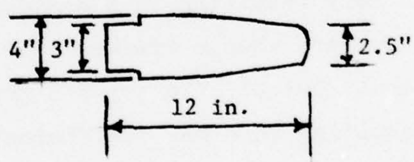
It was assumed that the penetration of the grousers for a tracked vehicle operating on in situ coal would be somewhat less than the penetration on soil and somewhat more than penetration on concrete.



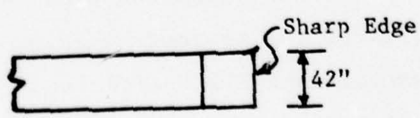
a. Top view of loader



b. View of vertical cutting edge



c. Typical side view of a cutting tooth



d. View of horizontal cutting edge

Figure 12. Generalized views of the Holland loader, Series H1

The maximum DBP coefficients on soil and on concrete were averaged to determine a maximum DBP coefficient on in situ coal. The maximum DBP coefficient for tracked vehicles operating on in situ coal was thus estimated to be 0.56. Using this value (0.56), the effective DBP-speed curves (Figures 7 and 8) for 300+ CI were adjusted. The new curves for the two configurations are shown in Figure 13. The data used to develop these curves are shown in Table 5.

Another value that was required to adequately estimate the loaders performance was the effective distance (D) forward of the cutting teeth at which the coal will be sheared. Previous studies at WES (Reference 11) concerning the penetration of a projectile into frozen ground indicate that the minimum distance forward of the point of the projectile affected by the penetration was equal to the radius of the projectile. Using this criterion along with the dimensions of the cutting teeth (Figure 12c) of the loader, D was estimated to be 1.25 in. Therefore, for the loader to operate it must be able to shear the coal to a depth of 1.25 in. parallel to the cutting edges and into the coal seam.

Using the physical dimensions shown in Figure 12, the value of D previously determined, the engineering properties of the coal, and the adjusted DBP predictions from AMM, an estimate of in situ coal moving rates for the two prime mover configurations was made. The applied procedure is outlined in detail in the following paragraphs.

From basic statics equations, the force developed by the prime mover must be greater than the shearing resistance of the coal for the loader to shear the in situ coal. Using the optimum speed of 1.6 mph, the optimum DBP's (from Table 5) are 98,500 and 155,860 lb for the D9G's and 41B's, respectively. These optimum rates are based on the traction capabilities of the machine rather than the size of the cutting blade.

Estimates of coal moving rates were made based on the power available from the prime movers and the power required to shear the in situ coal. The power available from the prime movers is based on optimum speed and DBP for the two configurations. The power required to shear the coal is based on the cutting area of the loader and the in situ shear strength of the coal. Assumptions used are as follows:

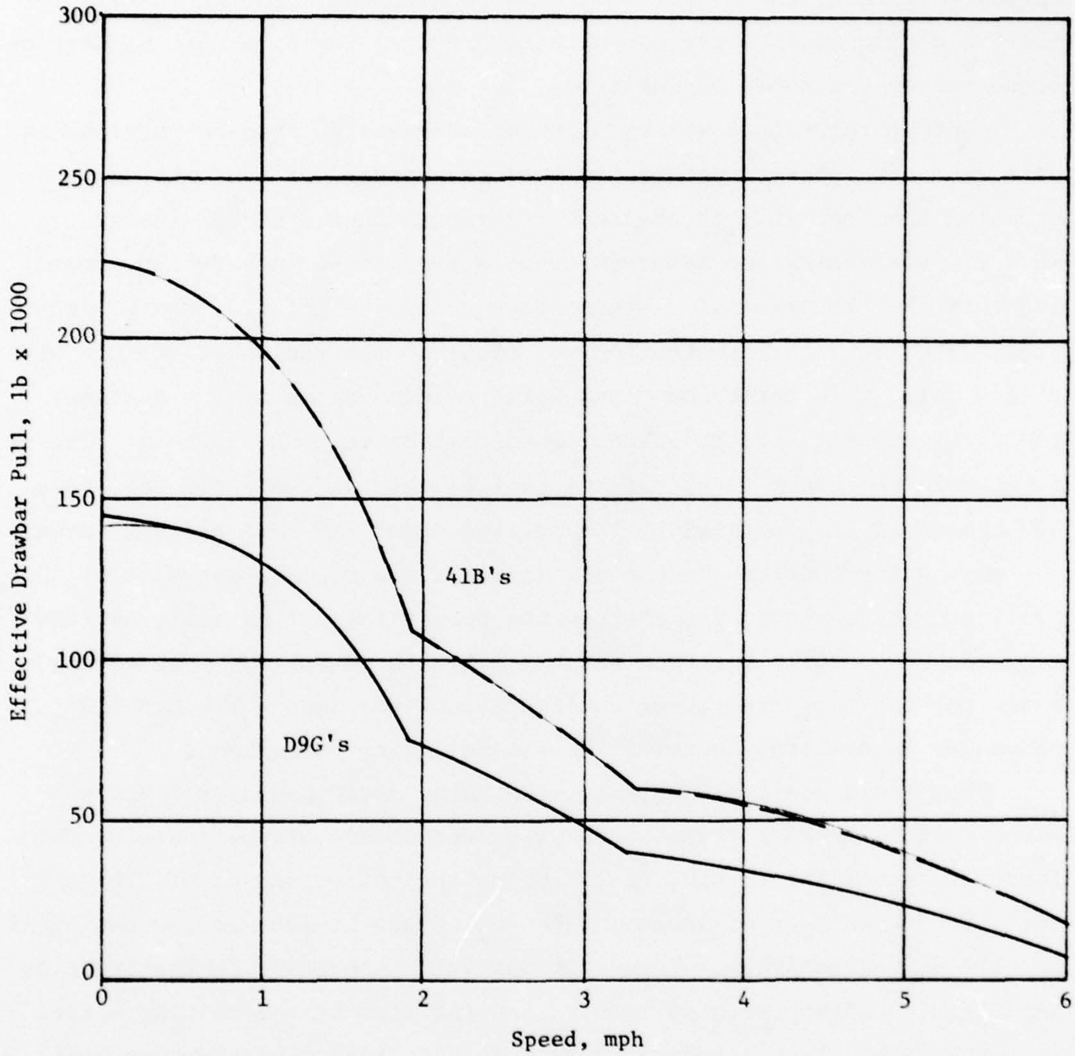


Figure 13. Effective drawbar pull versus speed for Holland loader, Series H1 with D9G and 41B prime movers on in situ coal

Table 5

Drawbar Pull and Speed Data for Holland Loader, Series H1 with D9G and 41B Prime Movers on In Situ Coal

Speed		Effective Drawbar Pull	
		2-D9G's	2-41B's
mph	fps	lb x 1000	lb x 1000
0.2	0.29	140.21	220.95
0.4	0.59	139.37	217.62
0.6	0.88	138.54	212.61
0.8	1.17	136.04	209.27
1.0	1.47	133.78	198.42
1.2	1.76	124.35	188.41
1.4	2.05	112.08	159.19
1.6	2.35	98.50	115.86
1.8	2.64	81.70	129.99
2.0	2.93	73.44	108.29
2.2	3.23	68.69	100.77
2.4	3.52	62.84	94.10
2.7	3.96	57.00	85.75
2.9	4.25	50.32	78.24
3.2	4.69	41.98	63.22
3.4	4.99	40.31	62.38
3.7	5.48	38.64	60.72
3.9	5.72	36.97	57.38
4.7	6.89	29.46	45.69
5.2	7.63	22.78	37.35
5.7	8.36	14.44	27.33
6.2	9.09	2.75	14.81

a. The average shearing stress (T) for in situ coal is equal to 367 psi.

b. The total cutting edge of loader will be functioning during optimum production.

c. The basic equations of mechanics of materials are valid.

d. The cohesion forces of the coal acting perpendicular to the cutting edges of the loader are negligible.

e. The effective distance (D) forward of the cutting edge is equal to 1.25 in.

f. The adjusted DBP predictions are adequate for predicting performance on in situ coal.

Calculations

A typical cross section of a full cut with the loader is shown below. The cross-hatched area borders the planes on which the coal will be sheared. The horizontal distance from the vertical cutting edge to the frog is 42 in. The prime movers must have sufficient power to passively shear the coal along this plane also.

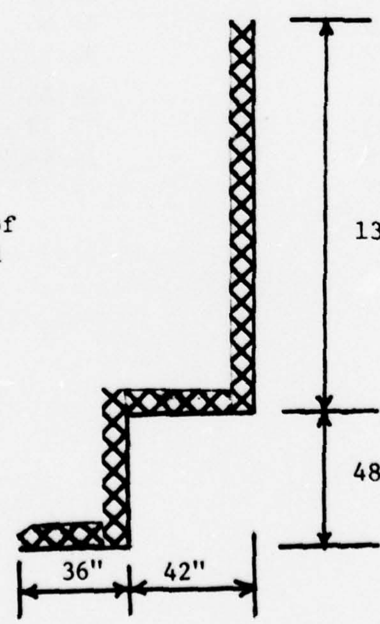


Figure 14. Cross section of a full cut with Holland loader, Series H1

D = 1.25 in. (into the coal seam)

A_T = total area to be sheared at any instant

A_T = (132 in. × 1.25 in.) + (42 in. × 1.25 in.) + (48 in. × 1.25 in.) + (36 in. × 1.25 in.)

A_T = 322.50 sq in.

Shearing stress (T) of the coal = 367 psi

Optimum vehicle speed (V_o) from AMM = 1.6 mph

From basic mechanics of materials:

$$\text{Shearing stress (T)} = \frac{\text{force applied (F)}}{\text{area on which force is applied (A)}} \tag{1}$$

T = 367 psi

$A = A_T$ = 322.50 sq in.

Set $F = F_r$

Where F_r = force required to shear 1.25 in. over the entire cutting edge

Then F_r = 367 psi (322.50 sq in.)

F_r = 118,357 lb

By definition power ($\overline{P}$) is restricted to mean the time rate of doing work. Then

$$\overline{P} = FV \tag{2}$$

Where F = applied force

V = speed at which force is being applied

Now setting $\overline{P} = \overline{P}_r$ where $\overline{P}_r$ = required power to shear coal

$F = F_r$ and $V = V_o$

Then $\overline{P}_r = F_r V_o$

$$\overline{P}_r = (118{,}357 \text{ lb}) \times (1.6 \text{ mph}) \times (5280 \frac{\text{ft}}{\text{mi}}) \times (\frac{1 \text{ hr}}{60 \text{ min}})$$

$$\overline{P}_r = 16{,}664{,}736 \frac{\text{ft-lb}}{\text{min}}$$

For the loader to shear the coal the power available ($\overline{P}_a$) from the prime movers must be greater than the power required ($\overline{P}_r$).

Vertical-cut belt loader
with D9G prime movers

At 1.6 mph the effective DBP (from AMM) = 98,500 lb

Using Equation 2

Set: $\overline{P}$ = power available ($\overline{P}_a$)

F = effective drawbar pull (DBP)

$V = V_o$

Then $\overline{P}_a = \text{DBP} \times V_o$

$$\overline{P}_a = 98{,}500 \text{ lb} \times (1.6 \text{ mph}) \times \left(5280 \frac{\text{ft}}{\text{mi}}\right) \times \left(\frac{1 \text{ hr}}{60 \text{ min}}\right)$$

$$\overline{P}_a = 13{,}868{,}800 \frac{\text{ft-lb}}{\text{min}}$$

The power available ($\overline{P}_a$) is less than the power required ($\overline{P}_r$); therefore, the loader with the D9G prime movers cannot shear the coal. Note: By using the maximum DBP coefficient on soil, with a 300+ CI, the effective DBP is 118,000 lb (Table 3) at optimum speed (1.6 mph) and the power available ($\overline{P}_a$) is 16,614,410 $\frac{\text{ft-lb}}{\text{min}}$, which is slightly less than the power required ($\overline{P}_r = 16{,}664{,}736 \frac{\text{ft-lb}}{\text{min}}$).

Vertical-cut belt loader
with 41B prime movers

At 1.6 mph the effective DBP = 155,860 lb

$$\overline{P}_r = 16{,}664{,}736 \frac{\text{ft-lb}}{\text{min}}$$

Using Equation 2

Set $\overline{P}$ = power available

F = effective DBP

$V = V_o$

$$\text{Then} \qquad \bar{P}_a = (155{,}860 \text{ lb}) \times (1.6 \text{ mph}) \times (5280 \frac{\text{ft}}{\text{mi}}) \times (\frac{1 \text{ hr}}{60 \text{ min}})$$

$$\bar{P}_a = 21{,}945{,}088 \frac{\text{ft-lb}}{\text{min}}$$

$$\bar{P}_a \quad (21{,}945{,}088 \frac{\text{ft-lb}}{\text{min}}) \quad > \bar{P}_r \quad (16{,}644{,}736 \frac{\text{ft-lb}}{\text{min}})$$

Therefore, the loader with the 41B prime movers can shear the coal at optimum speed (1.6 mph).

Since the theoretical calculations indicate that the vertical-cut belt loader with the 41B prime movers can shear in situ coal, the effective DBP-speed curve for in situ coal (Figure 13) was converted to a productivity-speed curve as shown in Figure 15. The data used to develop this curve are given in Table 6. The optimum rate is based on the traction capabilities of the machine rather than the size of the cutting blade. The coal was assumed to have an in situ density of 2122 lb/cu yd, and the cutting distance was assumed to be in 100-ft segments. For the in situ coal, the optimum speed is about 1.6 mph and the calculated optimum coal moving rate is about 6206 cu yd/hr.

The production rate arrived at above assume ideal conditions, i.e., 100 percent efficiency, 60 min of operating time per hour, zero turnaround time, constant working conditions, etc. Efficiencies are much lower in actual practice. Therefore, it must be emphasized that estimates of production capabilities should be based on sustained operations rather than short-term theoretical calculations and should consider various operational environments. It must also be cautioned that the estimates of in situ coal production are based on theoretical effective DBP coefficients with no consideration of the lubricating characteristics of coal dust. Therefore, the effective DBP coefficient could possibly be somewhat lower than the values used.

Figure 15. Estimated production rate versus speed for the Holland loader, Series H1 with 41B prime movers on in situ coal

Table 6

In Situ Coal Production Based on Drawbar Pull and Speed for Holland Loader, Series H1 with 41B Prime Movers

Speed mph	Speed fps	Effective Drawbar Pull lb x 1000	Effective Drawbar Pull Equivalent cu yd	Seconds per 100-ft Section	100-ft Sections Per Hour	cu yd/hr
0.2	0.29	220.95	104.1	344.8	10.4	1082.9
0.4	0.59	217.62	102.6	169.5	21.2	2174.2
0.6	0.88	212.61	100.2	113.6	31.7	3176.1
0.8	1.17	209.27	98.6	85.5	42.1	4151.9
1.0	1.47	198.42	93.5	68.0	52.9	4946.5
1.2	1.76	188.41	88.8	56.8	63.4	5629.2
1.4	2.05	159.19	75.0	48.8	73.8	5536.4
1.6	2.35	155.86	73.45	42.6	84.5	6206.5
1.8	2.64	129.99	61.3	37.9	95.0	5819.5
2.0	2.93	108.28	51.0	34.1	105.6	5388.5
2.2	3.23	100.77	47.5	31.0	116.1	5513.4
2.4	3.52	94.10	44.3	28.4	126.8	5622.9
2.7	3.96	85.75	40.4	25.3	142.3	5750.3
2.9	4.25	78.24	36.9	23.5	153.2	5648.6
3.2	4.69	63.22	29.8	21.3	169.0	5035.0
3.4	4.99	62.38	29.4	20.0	180.0	5291.4
3.7	5.43	60.72	28.6	18.4	195.7	5599.9
3.9	5.72	57.38	27.0	17.5	205.7	5562.2
4.7	6.89	45.69	21.5	14.5	248.3	5346.3
5.2	7.63	37.35	17.6	13.1	274.8	4836.8
5.7	8.36	27.35	17.6	13.1	274.8	3863.8
6.2	9.09	14.81	7.0	11.0	327.3	2284.3

Sample Calculation

Assume 2 mph (176 fpm), in-situ coal, and 2122 lb/cu yd
From AMM, DBP = 108,280 lb

$$\text{Equivalent cu yd} = \frac{129{,}750 \text{ lb}}{2122 \times \frac{\text{lb}}{\text{cu yd}}} = 51.0 \text{ cu yd}$$

$$\text{Time to move 100 ft} = \frac{100}{176} \times 60 = 34.1 \text{ sec}$$

$$\text{No. of 100-ft sections per hr} = \frac{3600}{34.1} = 105.6$$

$$\text{cu yd/hr} = 105.6 \times 51.0 \text{ cu yd} = 5388.5 \text{ cu yd/hr}$$

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the analysis, the following conclusions were drawn.

a. The Holland vertical-cut belt loader with either D9G or 41B prime movers appears to be capable of substantially fulfilling its manufacturer-predicted production rates provided it has good traction and can make a full, continuous cut in light to medium soils.

b. Sustained production rates will be much lower than the predicted maximum because relevant operating and environmental efficiency factors are not considered in the computations.

c. Conditions for optimum production did not exist at the Wyodak Mine, the Optima Dam construction site, or the hydroelectric plant construction site because the areas in which machines were operating did not allow the loader to make a full continuous cut.

d. Based on power available from the prime movers and power required to shear in situ coal, theoretical calculations indicate that the Holland loader with the D9G prime movers *could not load in situ coal.* The Holland loader with the 41B prime movers could, however.

Recommendations

Based on the results of this limited evaluation, the recommendations are as follows:

a. The Holland vertical-cut loader assembly should be field tested with both prime mover configurations in several types of overburden material and in situ coal to validate the theoretical estimates in this report.

b. Appropriate engineering data and detailed records of sustained production rates with the Holland vertical-cut loader in various types of material should be maintained by Bureau of Mines personnel in order to better evaluate its capabilities.

c. Drawbar pull-slip and pull-speed tests should be conducted on a range of tractors to develop soil- and coal-vehicle relations for tractor dozers.

d. Laboratory tests to determine shear strength, density, and other pertinent properties should be conducted on coal from various coal mines located throughout the United States.

e. Field tests should be conducted to determine the effective distance forward of the cutting edge of the loader at which coal will be sheared.

f. Carefully controlled tests be conducted to determine optimum production rates and the optimum tractor speed.

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3. U. S. Army Engineer Waterways Experiment Station Miscellaneous Paper M-76-2, "Limited Evaluation of Vertical-Cut Belt Loader in Overburden Removal and Surface Mining of Coal," Feb 1976.

4. U. S. Army Engineer Waterways Experiment Station Memorandum for Record, "Visit to Hardesty, Oklahoma, to Discuss and Observe the Performance of the Holland Loader," 29 Jul 1977.

5. U. S. Army Engineer Waterways Experiment Station Memorandum for Record, "Visit to Braidwood, Illinois, to Discuss and Observe the Performance of the Holland Loader," 31 Oct 1977.

6. Holland Construction Company, "Holland Loader," brochure, Billings, Mont.

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11. Ito, Y. Martin, Kreyenhagen Kin., Eggum, G. E. and Goerke, W. S., "Analysis of Dynamic Stresses Within a Terminal Delivery Vehicle During Penetration of a Hard Earth Target," Contract Report S-75-1, monitored by U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., Feb 1975.

APPENDIX A: CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report are converted to metric (SI) units as follows:

Multiply	By	To Obtain
U. S. Customary to Metric (SI)		
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
cubic yards per hour	0.7645549	cubic metres per hour
feet	0.3048	metres
feet per minute	0.3048	metres per minute
feet per second	0.3048	metres per second
foot-pounds (force)	1.355818	metre-neutons
gallons (U. S. liquid)	3.785412	cubic decimetres
horsepower (550 foot-pounds per second)	745.6999	watts
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres
miles (U. S. statute) per hour	1.609344	kilometres per hour
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic yard	0.5933	kilograms per cubic metre
square inches	0.000645	square metres
tons (mass)	907.1847	kilograms

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Green, Charles E
Limited evaluation of the Holland vertical-cut belt loader / by Charles E. Green. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.
60, 1 p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; GL-79-1)
Prepared for Office of the Assistant Director--Mining, Bureau of Mines, U. S. Department of Interior, Washington, D. C., under Contract No. H0252009, Modification 3.
References: p. 60.

1. Belt conveyors. 2. Coal. 3. Earth handling equipment. 4. Evaluation. 5. Loaders. 6. Mobility. 7. Overburden. 8. Tractors. I. United States. Bureau of Mines. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; GL-79-1.
TA7.W34m no.GL-79-1